

Five Essays on International Spillovers of Monetary Policy, Fiscal Policy and Financial Markets

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Contents

I. Nicht-Technische Zusammenfassung	1
II. Preface	7
III. Studying Spillovers in a New Keynesian Continuous Time Framework with Financial Markets	11
III.1. Introduction	13
III.2. The Baseline Model	15
III.2.1. Households	15
III.2.2. Firms	17
III.2.3. Intermediate Firms	17
III.2.4. Wage Setting	18
III.2.5. The Financial Sector	18
III.2.6. The Monetary Reaction Function	20
III.2.7. Market Clearing	21
III.3. Linearisation and Continuous Time	21
III.3.1. Linearisation	21
III.3.2. Continuous-Time Modelling	22
III.4. Comparison of Discrete- and Continuous-Time Results in the Standard Model	24
III.5. Employing Empirically Estimated Parameters: The United States	26
III.6. Conclusions	27
III.7. Appendix	29
III.7.1. Technical Appendix	29
III.7.2. Figures and Tables	38
IV. Analysis of Monetary Policy Responses After Financial Market Crises in a Continuous Time	
New Keynesian Model	49
IV.1. Introduction	51

IV.2. Derivation of the Theoretical Model	54
IV.2.1. Placing the Model in the Literature	54
IV.2.2. Households	54
IV.2.3. Domestic Firms	58
IV.2.4. Intermediate Firms	59
IV.2.5. Wage Setting	60
IV.2.6. The Financial Sector	60
IV.2.7. The Monetary Policy Reaction Function	63
IV.2.8. Market Clearing	63
IV.3. The Continuous-Time Framework	64
IV.4. Studying the Reaction of Monetary Policy After a Financial Market Crash	65
IV.4.1. Simulating Economies	65
IV.4.2. Employing Empirically Estimated Parameters	68
IV.5. Conclusions	69
IV.6. Appendix	72
IV.6.1. Technical Appendix	72
IV.6.2. Figures and Tables	85
 V. Monetary and Fiscal Policy in Times of Crises: A New Keynesian Perspective in Continuous Time	 97
V.1. Introduction	99
V.2. The Model	101
V.2.1. The Demand Side	102
V.2.2. The Supply Side	105
V.2.3. Wage Setting	106
V.2.4. The Exchange Rate and the Uncovered Interest Rate Parity	107
V.2.5. Financial Sector	107
V.2.6. Fiscal and Monetary Policy Authorities	109
V.2.7. Market Clearing	110
V.2.8. The Special Case of a Monetary Union	111
V.3. Continuous-Time Framework	111
V.4. Model Calibration	113
V.5. Simulation Results	114
V.6. Conclusion	116

V.7. Figures and Tables	119
VI. Identification Through Heteroscedasticity in a Multicountry and Multimarket Framework	127
VI.1. Introduction	129
VI.2. Methodology	131
VI.3. Data and Empirical Results	134
VI.4. Conclusions	137
VI.5. Tables	139
VII. Spillover Effects in Government Bond Spreads: Evidence from a GVAR Model	147
VII.1.Introduction	149
VII.2.Literature Overview	150
VII.3.The GVAR Approach	153
VII.4.Data	156
VII.5.Estimation	160
VII.5.1.Impulse Response Functions	161
VII.5.2.Variance Decomposition	162
VII.6.Conclusion	163
VII.7.Figures and Tables	165
VIII.Final Remarks	181
IX. Bibliography	185

List of Tables

III.1. Parameters, Priors and Posteriors	47
IV.1. Priors and Posteriors	93
IV.2. Extreme Values of the Simulated NK model: Maximum	95
IV.3. Extreme Values of the Simulated NK Model: Minimum	95
V.1. Parameters	123
V.2. Extreme Values - Open-Economy Simulations	124
V.3. Extreme Values - Monetary Union Model	125
VI.1. Descriptive Statistics of the Monetary Policy Rate	140
VI.2. GMM Results, 1/5	141
VI.3. GMM results, 2/5	142
VI.4. GMM results, 3/5	143
VI.5. GMM results, 4/5	144
VI.6. GMM results , 5/5	145
VII.1.Data Sources	174
VII.2.Principal Component Analysis	174
VII.3.Descriptive Statistics for Sovereign Bond Spreads	174
VII.4.Contemporaneous Effects	175
VII.5.Power of explanation for the individual estimations	176
VII.6.Variance decomposition for the entire dataset	177
VII.7.Variance decomposition for the entire dataset	178
VII.8.Variance decomposition since the onset of the Eurzone	179

List of Figures

III.1. Contractionary Monetary Policy Shock in Discrete time	39
III.2. Contractionary Monetary Policy Shock in Continuous time	40
III.3. Negative Bond Market Shock in Discrete Time	41
III.4. Negative Bond Market Shock in Continuous Time	42
III.5. Negative Stock Market Shock in Discrete Time	43
III.6. Negative Stock Market Shock in Continuous Time	44
III.7. Impulse Response Function: USA	45
IV.1. Monetary Policy Shock - Modified Monetary Policy	86
IV.2. Minor Stock Market Crisis - Modified Monetary Policy	87
IV.3. Minor Stock Market Crisis - Standard Monetary Policy	88
IV.4. Stock Market Crisis - Modified Monetary Policy	89
IV.5. Stock Market Crisis - Standard Monetary Policy	90
IV.6. Housing Market Crisis - Modified Monetary Policy	91
IV.7. Housing Market Crisis - Standard Monetary Policy	92
V.1. Spending-oriented Fiscal Policy, Modified Taylor Rule	120
V.2. Austere Fiscal Policy, Modified Taylor Rule	121
V.3. Monetary Union, Spending-oriented Fiscal Policy, Modified Taylor Rule	122
VI.1. Euribor volatility: comparison of monetary policy action dates and the respective non- monetary policy date	136
VII.1.Co-movement of real and financial Euro variables.	166
VII.2.Co-movement of real and financial Euro variables.	166
VII.3.Co-movement of real and financial Euro variables.	166
VII.4.Shock on the US Stock Market	167
VII.5.Shock on the US Stock Market	167

VII.6.Shock on the US Stock Market	167
VII.7.Shock on the Greek Stock Market	168
VII.8.Shock on the Greek Stock Market	168
VII.9.Shock on the Greek Stock Market	168
VII.10 Shock on Volatility, starting in the United States	169
VII.11 Shock on Volatility, starting in the United States	169
VII.12 Shock on Volatility, starting in the United States	169
VII.13 Shock on Volatility, starting in Greece	170
VII.14 Shock on Volatility, starting in Greece	170
VII.15 Shock on Volatility, starting in Greece	170
VII.16 Shock on Liquidity, starting in the United States	171
VII.17 Shock on Liquidity, starting in the United States	171
VII.18 Shock on Liquidity, starting in the United States	171
VII.19 Shock on Liquidity, starting in the Greece	172
VII.20 Shock on Liquidity, starting in the Greece	172
VII.21 Shock on Liquidity, starting in the Greece	172
VII.22 Shock on the Money Market, starting in the United States	173
VII.23 Shock on the Money Market, starting in the United States	173
VII.24 Shock on the Money Market, starting in the United States	173

Chapter I.

Nicht-Technische Zusammenfassung

Die aktuelle Finanz- und Schuldenkrise hat die Fiskal- und Geldpolitik sowie Finanzmärkte in den Fokus akademischer Forschung und der Gesellschaft insgesamt gebracht. Insbesondere hat die Krise auch die internationalen Zusammenhänge und Transmissionen von Schocks aufgezeigt: ökonomische Schocks streuen auf andere Märkte und greifen auf andere Länder über, mit teilweise schwerwiegenden Effekten. Das bessere Verständnis dieser Zusammenhänge kann daher einen signifikanten Einfluss auf internationale Politik haben und diese maßgeblich verbessern. Politiker können so koordiniert Fiskal- und Geldpolitik betreiben, wobei Fiskalpolitiker zur Stabilisierung der Märkte zwischen Ausgabenpolitik und Sparpolitik entscheiden müssen während Geldpolitiker mit dem Problem der Nullzinsgrenze umgehen müssen. Insbesondere der Einfluss von Finanzmärkten und wie die Politik, vornehmlich die Geldpolitik, auf diese reagieren soll und wenn ja in welchem Ausmaß, wird seit der Finanzkrise 2007/2008 von Wirtschaftsforschern weltweit analysiert und diskutiert.

Es sind viele verschiedene methodische Ansätze der Geldpolitik entwickelt worden, um trotz niedriger Zinsen und der damit verbundenen Annäherung an die Nullzins-Untergrenze effektiv Geldpolitik betreiben zu können. Quantitative Easing ist eine dieser unkonventionellen Methoden und vermutlich auch die Bekannteste. Der Erfolg dieser Politikmaßnahme war jedoch geringer als erhofft, so dass es bis zu diesem Zeitpunkt keine Lösung des Problems der Nullzinsuntergrenze gibt. Diese Dissertation hilft bei der Lösungsfindung, indem sie die Zusammenhänge von Geld- und Fiskalpolitik und internationalen Finanzmärkten untersucht. Dabei werden theoretische und empirische Verfahren verwendet. Das theoretische Modell ist in kontinuierlicher Zeit geschrieben, um so mehrere Probleme der makroökonomischen Standardmodelle anzugehen. Empirische Evidenz wird anhand von verschiedenen Methoden bewerkstelligt: Bayesianische Schätzungen von dynamischen stochastischen Gleichgewichtsmodellen (DSGE), ein weiterentwickelter allgemeiner Momentenschätzeransatz (GMM) und Kleinste-Quadrate-Schätzung eines globalen vektorautoregressiven Modells (GVAR).

Auf Grund der Globalisierung und der Integration von Märkten sowie wegen der modernen Informationstechnologien reagieren die Finanzakteure und damit die Finanzmärkte sofort, teilweise in Tausendstelsekunden, auf verschiedene Nachrichten. Die Transmission von Nachrichten in die Kurse von Aktien und Bonds und anschließend in die Realwirtschaft erfolgt dabei über verschiedene Kanäle. Annähernd alle makroökonomischen Modelle sind jedoch in diskreter Zeit verfasst und können diese Hochfrequenz-Fluktuationen nicht einfangen und daher auch nicht erklären. In Kapitel 1 dieser Dissertation wird daher ein Standard DSGE Modell genommen und von der diskreten in die kontinuierliche Zeit übertragen. Dadurch kann das nicht-lineare Modell numerisch gelöst werden. Weiterhin kann mit Hilfe dieses Vorgehens auch die Zinsstruktur eingebunden und untersucht werden. Einer Analyse der Resultate des nicht-linearen Modells mit kalibrierten Parameterwerten folgt im Anschluss eine Schätzung des nicht-linearen

Modells in kontinuierlicher Zeit.

In Kapitel 2 wird zunächst das kontinuierliche Modell mit dem Standardmodell in diskreter Zeit verglichen. Das Standard DSGE Modell, welches von Smets & Wouters eingeführt wurde, wird formal hergeleitet und in die kontinuierliche Zeit übertragen. Dazu werden stochastische Differentialgleichungen verwendet. Gleichzeitig wird die Zinsstruktur eingebaut, so dass die Analyse eines Finanzmarktes möglich ist. Dann werden verschiedene Schocks wie ein geldpolitischer Schock oder ein Finanzschock simuliert, um Standardergebnisse des diskreten Modells zu replizieren. Ein direkter Vergleich der Impuls-Antwort-Folgen zeigt, dass der Anpassungsprozess zwar analog verläuft, jedoch weist das Modell in kontinuierlicher Zeit mehr kurzfristige Fluktuationen auf. Dadurch eignet es sich besser für die Analyse von Konjunkturzyklen. Im Anschluss wird das Modell bayesianisch geschätzt auf der Grundlage von makroökonomischen Daten der Vereinigten Staaten von Amerika. Die geschätzten Mittelwerte der Parameter und deren Verteilungen entsprechen den gängigen Werten wie derer oben angeführten Autoren. Die geschätzten Ergebnisse belegen die theoretischen Überlegungen.

Um das Modell in einer offenen Volkswirtschaft anzuwenden, wird es entsprechend um eine ausländische Ökonomik erweitert in Kapitel 3. Insbesondere wird auch hier ein Finanzmarkt in die Modell-Ökonomie integriert, hierbei werden Erkenntnisse und Modellierungen aus der Finance Literatur verwendet: für Wertpapiere wird ein jump-diffusion Modell angewandt. Die Einbindung von Finanzmärkten im Modell führt dazu, dass eine gegenseitige Beeinflussung und Rückwirkung zwischen der Realwirtschaft und der Finanzwirtschaft entsteht. So können wir neben den gewöhnlichen Modellvariablen makroökonomische Einflüsse auf Aktienmärkte berücksichtigen und analysieren.

Für die Rolle der Geldpolitik in einer offenen Welt mit kompletten Finanzmärkte zu verstehen, werden mehrere Simulationen durchgeführt. Es wird zwischen einer klassischen, ruhigeren Geldpolitik, die auf Änderungen in der Produktion und der Inflationsrate reagiert, und einer aktiven Geldpolitik, die zusätzlich zu den traditionellen Zielvariablen auch sofort auf einen Finanzmarktaufbruch reagiert, unterschieden. Um die aktuelle Finanzkrise, die ihren Ursprung auf dem US-amerikanischen Häusermarkt hatte, zu analysieren, wird ein Hauspreis-Index eingefügt. Die Ergebnisse weisen darauf hin, dass eine schnell reagierende Geldpolitik mit Fokus auch auf Finanzmarktvariablen die Folgen von Finanzkrisen mildern kann, allerdings zum Preis von höherer Volatilität der Inflationsrate. Das theoretische Modell der offenen Volkswirtschaft wird, wie in Kapitel 2 mit der geschlossenen Volkswirtschaft geschehen, empirisch belegt. Hierbei werden Daten aus den Vereinigten Staaten von Amerika und Kanada verwendet. Die Ergebnisse untermauern die Resultate des theoretischen Modells mit kalibrierten Parameterwerten. Weiterhin werden die Übertragungseffekte der Geldpolitik auf die Finanzmärkte geschätzt. Auch diese Ergebnisse unterstützen unsere Annahmen einer globalen, stark miteinander verknüpften (Wirtschafts-

)Welt.

Der Einfluss der Fiskalpolitik wird darüber hinaus auch berücksichtigt. Dazu wird das Modell in Kapitel 4 erweitert, so dass Geld- und Fiskalpolitik sowie ihre Wechselwirkungen in einer offenen Volkswirtschaft untersucht werden können. Dabei wird zwischen Ausgaben- und Sparpolitik auf fiskalischer Seite unterschieden. Das Modell zeigt, dass es im Allgemeinen keine optimale Fiskalpolitik gibt, um eine Krise zu überwinden. Abhängig vom Grad der Finanzmarktintegration und der Verbundenheit zweier Volkswirtschaften sowie der Risikoaversion bezüglich der öffentlichen Schulden ist entweder Ausgaben- oder Sparpolitik zielführender zur Stabilisierung einer Ökonomie. Als allgemeingültiges Ergebnis stellen wir fest, dass sich die Geldpolitik als besser erweist, um eine Finanzkrise zu überwinden – eine koordinierte, unterstützende Fiskalpolitik jedoch ist die beste Methode.

Die in den ersten Kapiteln durchgeführten Untersuchungen auf Basis verschiedener DSGE Modelle werden in den nachfolgenden Kapiteln durch weniger modell-theoretische Ansätze ergänzt. Neben der Bayesianischen Schätzung können durch andere statistische Verfahren weitere Erkenntnisse der internationalen Auswirkungen von Geld- und Fiskalpolitik sowie Finanzmärkten gewonnen werden. Dazu wird zunächst in Kapitel 5 ein allgemeiner Momentenschätzer verwendet, der die Heteroskedastie in den Daten ausnutzt und so die Wechselwirkungen von den Finanzmärkten und der Geldpolitik untersucht. Des Weiteren wird in Kapitel 6 ein globales VAR verwendet, um den Einfluss von Staatsanleihen auf makroökonomische Variablen zu ermitteln. Auch hier liegt der Fokus auf den Wechselwirkungen von Geldpolitik, Fiskalpolitik und Aktienmärkten.

In Kapitel 5 wird hierzu der Ansatz eines allgemeinen Momentenschätzers verwendet, welcher die Heteroskedastie in den Daten ausnutzt, um geldpolitische Ereignisse und deren Einfluss auf verschiedene Variablen zu identifizieren. Das ist eine Schätzmethode, die mehrere Mängel gängiger Event-Study Verfahren überwindet. So kann Geldmengenpolitik in einem multinationalen Kontext ausführlich analysiert werden. Es wird ein Datensatz mit Zeitreihen verschiedener OECD Länder verwendet: die Vereinigten Staaten von Amerika, Kanada, Japan, das Vereinigte Königreich, Deutschland, Frankreich, Spanien, Irland und Griechenland. Wir legen überschwappende Effekte von geldpolitischen Institutionen wie der Federal Reserve oder der europäischen Zentralbank auf die globalen Märkte offen. Die Resultate deuten darauf hin, dass Zentralbanken, die auf Grund ihres gesetzlichen Mandats nur zu der Beobachtung der nationalen makroökonomischen Variablen verpflichtet sind, die Übertragungseffekte auf andere Volkswirtschaften berücksichtigen sollten, wenn sie optimale Geldpolitik betreiben wollen.

In dem letztem Kapitel 6 wird der Zusammenhang von internationalen Staatsanleihen, Aktienmärkten und Geldpolitik analysiert. Hier wird ein globales VAR-Modell verwendet, um die kontemporären und zeitlich versetzten Wechselwirkungen zu identifizieren und analysieren. Das Modell berücksichtigt

die markt- und länderübergreifenden Effekten einer stark vernetzten Weltwirtschaft. Weiterhin können schwach exogene Variablen, deterministische Trends und eine Zeitkomponente eingebunden werden, was eine konsistente Schätzung der Koeffizienten ermöglicht und damit verlässlichere Ergebnisse zur Untersuchung erlaubt. Ferner kann hierdurch auch die Veränderung der Wechselwirkungen zwischen unterschiedlichen Stichproben berücksichtigt werden. Zudem erlaubt die Methodik die individuelle bilaterale Gewichtung der Übertragungseffekte zwischen zwei verschiedenen Volkswirtschaften anhand des jeweiligen Schuldenstandes eines Landes. In der Summe kann dadurch das GVAR die Staatsanleihenmärkte besser beschreiben als ein Standard-VAR Modell und ist folglich für die durchgeführte Analyse wesentlich besser geeignet als der übliche Ansatz.

Die Ergebnisse führen zu der Erkenntnis, dass es in der Tat länder- und marktübergreifende Effekte auf Wirtschaften gibt. Die Resultate offenbaren ferner, dass von Schocks mit Ursprung in den Vereinigten Staaten von Amerika starke Übertragungseffekte in den "Rest der Welt" ausgehen. So haben diese Schocks einen großen Effekt auf OECD-Länder außerhalb der Eurozone. Aber auch die entwickelten Volkswirtschaften des europäischen Kontinents werden von US-amerikanischen Entwicklungen geprägt, die hoch verschuldeten Eurozonenländer wie Griechenland leiden unter einer verhältnismäßig starken Verwundbarkeit gegenüber den Geschehnissen auf der anderen Seite des Atlantiks. Auf der anderen Seite übertragen sich Schocks aus europäischen Volkswirtschaften weniger stark als vermutet auf Länder außerhalb der Eurozone. Nichtsdestotrotz haben unerwartete Ereignisse innerhalb der Eurozone einen größeren Übertragungseffekt auf Nicht-Eurozonenländer als vergleichbare Schocks aus den Vereinigten Staaten von Amerika.

Chapter II.

Preface

The recent financial crisis and the subsequent sovereign debt crisis have put fiscal and monetary policy-makers, as well as financial market participants, in the spotlight of academic research and society. The crisis has also shown how interconnected the world is, with shocks to countries or economic areas spreading rapidly across borders with considerable international effects. Hence, there is a need for policy-makers to better understand the impact of monetary and fiscal policy and the effects of coordinated policies in an international environment where public debt is high and vulnerability to fiscal and financial crisis is increasing. On the one hand, fiscal policy-makers must choose between austerity and spending measures while on the other hand monetary policy-makers struggle to formulate policy at the lower bound.

Although many non-standard measures, such as quantitative easing, have been developed to overcome the crisis, there has been no solution to date. This research aims to help understand the interactions between monetary policy, fiscal policy and financial markets. The fundamental methods utilised in this dissertation are twofold; the theoretical model incorporates financial markets, monetary policy and fiscal policy while the empirical evidence analyses whether the theoretical foundation has some real evidence. The theoretical model is conducted in continuous time to overcome several shortcomings in the standard macroeconomic analysis. Empirical evidence is provided by three types of estimation techniques - Bayesian estimation, GMM estimation and a Global VAR analysis.

With the vast advance in globalisation, economic integration and information technology in the modern era, news arrives at shorter intervals and economic activities take place in a non-stop fashion. Standard macroeconomic models in discrete time cannot capture these small fluctuations. In particular, when analysing financial markets, these fluctuations are crucial. To build a bridge between well-established finance and macroeconomic research, a theoretical foundation of the standard DSGE model in a closed economy is developed in Chapter 4. This model has several advantages over standard models. First, it can be solved non-linearly conducting numerical techniques. Second, it has a well-defined term structure which allows for including financial markets. Third, estimating the non-linear model is easier when using continuous time.

The model captures all standard findings of macroeconomic research. It is then compared to its discrete time component to contrast both approaches. Continuous time is superior in that case as it captures more fluctuations. Furthermore, some monetary policy experiments were conducted to obtain a first impression of the applicability of the model. To provide empirical evidence, parameters were estimated using Bayesian estimation for continuous time. The model is extended to the open economy in Chapter 5. Furthermore, the extended model not only incorporates standard assets, but it also allows for the analysis of bonds or even call and put prices. Therefore, a complete financial market is incorporated that

combines well-established stochastic models in finance such as the stochastic jump-diffusion model or the Vasicek model.

To understand monetary policy in a world with a complete financial market, some experiments were conducted. There is a differentiation between a monetary policy which reacts immediately to financial market turmoil and a classic, calmer monetary policy which reacts to changes in output and the inflation rate. To account for the onset of the recent financial crisis, a housing market index is included. The results suggest that for the price of a strong hike in inflation, a severe economic recession can be avoided under the modified rule. The theoretical model is put into data by comparing parameter estimations with data from the United States and Canada using Bayesian continuous time estimation. The results again support the theoretical foundation of the model. Moreover, the spillovers from monetary policy to the financial markets were also estimated. The estimation results show, that there are spillover effects from the United States to Canada. Moreover, results suggest that there is no linkage the other way round.

To account for the recent sovereign debt crisis, a fiscal authority is implemented in this model in Chapter 6. In this case, the open-economy model includes a fiscal and monetary authority to overcome economic crises. The model shows that there is no best way to overcome a crisis in all cases. Depending on the amount of interaction, risk aversion and household preferences regarding public debt austerity or spending measures are adequate. Furthermore, depending on the fiscal policy, monetary policy must be more pro-active. However, there are some general findings. All in all, monetary policy proves to be better than fiscal policy in overcoming a financial crisis. Moreover, fiscal policy supports monetary policy in the process of conducting policy.

Apart from using Bayesian continuous time estimation, further insights can be gained by using other estimation techniques. To understand the spillover effects of financial markets, monetary policy and fiscal policy in the real world, estimations are conducted. On the one hand, Chapter 7 presents a GMM estimation technique which allows for an advanced event study analysis of monetary policy and the reaction to and from financial markets in a globalised world. On the other hand, Chapter 8 provides an insight into the understanding of the driving factors of sovereign bond spreads to account for the interdependencies of fiscal factors, government debt and financial markets.

In Chapter 7, the identification through heteroscedasticity approach is applied. This is an estimation technique which overcomes some shortcomings of an event study by deriving an instrument, respectively moment conditions, within the data. Therefore, monetary policy can be explicitly analysed in a multinational framework. Major OECD countries are analysed, namely the United States, Canada, Japan, the United Kingdom, Germany, France, Spain, Ireland and Greece. We detect spillover effects from major monetary policy institutions to global markets. Thus, the central banks, which are legally obliged to

focus on their domestic areas, ought to be aware of the spillover effects their monetary policy actions have on other financial markets.

In Chapter 8 there is an analysis of linkages of international bond and stock markets, also including monetary effects. The analysis is conducted using a Global VAR approach. This approach covers the interdependencies across markets and across countries. It also allows for weakly exogenous variables, deterministic trends and a time-varying component. Furthermore, it weights the interaction due to a countries respective fiscal position relative to another. In this way the GVAR approach is superior over a classic VARX analysis as it covers the internationality and also superior over a panel VAR as it accounts for the countries relative fiscal position to each other.

Results show that there are spillovers across markets and nations. Furthermore, US shocks affect European countries which are highly indebted, but not stable Eurozone countries. However, shocks within Europe affect Eurozone countries but not non-Eurozone OECD countries. We also find a high impact of Federal Reserve policy to Greek bonds, however the effect diminishes rapidly. Analysing the effect since the inauguration of the monetary union only, support the overall results.

Chapter III.

Studying Spillovers in a New Keynesian Continuous Time Framework with Financial Markets

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Abstract

The recent financial and real economic crises have made it clear that macroeconomists need to better account for the influence of financial markets. This paper explores the consequences of treating the interaction between different financial markets, monetary policy, and the real economy seriously by developing a fully dynamic theoretical model in continuous time. Starting from a standard New Keynesian framework, we reformulate and extend the model by means of stochastic differential equations so as to analyse spillover effects and steady-state properties. We solve the nonlinear model using stochastic differential equations rather than third-order perturbation. Applying Bayesian estimation methods, we estimate the model for the US economy and analyse the financial markets influence on business cycles and monetary policy.

KEYWORDS: New Keynesian Model, Phillips Curve, Taylor Rule, Stochastic Differential Equations

JEL CLASSIFICATION: C02, C63, E44, E47, E52, F41

III.1. Introduction

The recent economic crisis emphasises the relevance of financial markets to macroeconomic stability. This should not be a surprise: financial markets played an important role in previous major crises too, such as the Great Depression and the Asian financial crisis. Arguably, these crises were associated with financial market turmoil and each required a different stabilisation policy to avoid further financial contagion. The Asian crisis was caused by speculative attacks on the Thai Baht and the Great Depression followed a major stock market crash. The ongoing European sovereign debt crisis was triggered by speculative attacks on government bonds following an increase in public debt, which debt was at least partly incurred as a result of government intervention in the banking sector in the aftermath of the recent financial crisis.

In light of this situation, we believe it is crucial to achieve a better understanding of the role different financial markets play in a macroeconomy. Furthermore, observing not only financial market actions but also financial market reactions to different policies could be helpful in designing appropriate policies. Put differently, policymaker responses to shocks could likely be improved by the availability of a thorough theoretical framework. However, the common macroeconomic approaches to monetary policy taken by central banks, both analytically and empirically, tend to downplay the role the financial system plays in the conduct of monetary policy and rarely, if ever, take into consideration different financial markets. Thus, we argue that academic research can assist central banks by placing greater emphasis on financial markets and moving beyond common macroeconomic models. Therefore, the purpose of this paper is to explore the consequences of treating seriously the interaction between financial markets, monetary policy and the real economy by developing a fully dynamic theoretical modelling framework. We are particularly interested in the relationship between financial markets and monetary policy, which is characterised by a substantial degree of simultaneity. We use stochastic differential equations to cope with the likely nonlinearity of macroeconomic relationships. We thus avoid third-order perturbation methods and can more easily estimate the model. Furthermore, Yu (2013) emphasises that there are compelling reasons why continuous-time models should appeal to both economists and financial specialists, one of these being that 'the economy does not cease to exist in between observations' (Bartlett 1946). Moreover, at an aggregate level, economic decision-making almost always involves many agents and is typically conducted over the course of a month and thus continuous-time models may provide a good approximation of the actual dynamics of economic behaviour. Another important advantage of continuous-time models is that they provide a convenient mathematical framework for the development of financial economic theory, enabling relatively simple and often analytically tractable ways to price financial assets. Continuous-time models also permit treating stock and flow variables separately. Finally, by using this

class of models, a well-defined mathematical analysis of model stability can be applied (Thygesen 1997).

In mainstream macroeconomic research, the New Keynesian (NK) model (Blinder (1997), Clarida, Gali and Gertler (1999), Romer (2000a) and Woodford (1999)) is a frequent starting point for analysing monetary policy. We follow this strand of literature and adopt the NK model as our baseline approach. However, as our main question of interest is the interaction between monetary policy and financial markets, we need to extend the NK model. Our starting point is that monetary policy reacts to financial markets and financial markets react to monetary policy and that this relationship is characterised by a notable degree of simultaneity. This is not a new idea; other studies have taken such simultaneity into account. However, most of this work is empirical in nature, for example, Bjornland and Leitemo (2009a), Rigobon (2003) and Rigobon and Sack (2003b). Rigobon (2003) and Rigobon and Sack (2003b) observe the effects of bonds and stocks on monetary policy and vice versa by applying a novel approach (identification through heteroscedasticity) to circumvent simultaneity issues. Bjornland and Leitemo (2009a) adopt a VAR approach to study how financial markets affect monetary policy. Technically, the authors deal with the simultaneity issue by imposing *a priori* short-run and long-run restrictions. Both studies find evidence of monetary policy reaction to financial market developments.

Less formally, Hildebrand (2006) argues that financial markets are the link between monetary policy and the real economy and are an important part of the transmission mechanism for monetary policy. Moreover, he argues that financial markets reflect expectations about future inflation and output and, therefore, are also affected by monetary policy. Christiano, Ilut, Motto and Rostagno (2008) propose a more formal empirical approach. When considering the problem of boom-bust cycles in the economy, they find evidence that it might be more expedient for monetary policymakers to target credit growth instead of inflation.

Our paper makes several contributions to the literature. First, we combine and extend the models of Smets and Wouters (2002) and Bekaert, Cho and Moreno (2010) and compute a closed-economy New Keynesian model that includes a financial market sector. Derivation of the monetary policy rule is in line with Smets and Wouters (2002). We follow Bekaert, Cho and Moreno (2010), Brunnermeier and Sannikov (2012) and Christiano, Motto and Rostagno (2014) for our modelling of a financial market sector.

Second, we undertake a formal mathematical analysis of the extended model in a continuous-time framework. This requires transforming the NK model in stochastic differential equations, using numerical algorithms to derive stable solutions, and studying the evolution of various variables over time. Our reading of the literature is that this combination of applying Taylor rules to financial markets and extending the NK model with two dynamic financial market equations is unique.

Third, we estimate model parameters for the United States using Bayesian estimation techniques and compare the estimated impulse-response functions with those from the theoretical simulations.

Our approach is similar to that taken by Asada, Chen, Chiarella and Flaschel (2006) and Chen, Chiarella, Flaschel and Hung (2006) and to Fernández-Villaverde, Posch and Rubio-Ramírez (2011). These authors transform the Keynesian AS/AD model into a disequilibrium model with a wage-price spiral and include two Phillips curves, one targeting wages and the other targeting prices. The model is transformed into five differential equations-explaining real wages, real money balances, investment climate, labour intensity, and inflationary climate-and its dynamics are analysed extensively. Malikane and Semmler (2008b) extend this framework by including the exchange rate and Malikane and Semmler (2008a) consider asset prices. However, none of these studies include both stock and bond markets. Since our aim is to close the gap between classic macroeconomic research and finance, we employ a discrete-time model as a starting point.

In the next section, we develop the theoretical baseline model. Section 3 contains the derivation of the continuous-time model. In Section 4, we compare discrete- and continuous-time results of the model. Section 5 contains an analysis employing empirically estimated parameters for the United States. Section 6 concludes.

III.2. The Baseline Model

Our model is based on the New Keynesian model of Smets and Wouters (2002, 2007) (respectively Allsopp and Vines (2000), Blanchard (2007, 2008), Clarida, Gali and Gertler (1999) and Gali and Monacelli (2005)).

III.2.1. Households

We assume that the economy is inhabited by a continuum of infinitely-living consumers $i \in [0, 1]$. First, we consider a consumption index, such as that of Dixit and Stiglitz (1977), $C_t (P_t)$ which consists of goods c_t^j produced by firm j . η_c is the elasticity of demand. Similarly, we define a production price index P_t , using p_t^j .

$$C_t = \left[\int_0^1 (c_t^j)^{\frac{\eta_c - 1}{\eta_c}} dj \right]^{\frac{\eta_c}{\eta_c - 1}} \quad (\text{III.1})$$

Accordingly, the aggregate price index (the CPI) is given by

$$P_t = \left[\int_0^1 (P_t^j)^{1-\eta_c} dj \right]^{\frac{1}{1-\eta_c}} \quad (\text{III.2})$$

Consumption is maximised subject to $\int_0^1 (P_t^j C_t^j) dj = Z_t$, where Z_t are expenditures.

$$C_t^j = \left(\frac{P_t^j}{P_t} \right)^{-\eta_c} C_t \quad (\text{III.3})$$

Our discrete time model is based on Smets and Wouters (2002, 2007). We extend it, following Paoli, Scott and Weeken (2010a), by including assets in the household's budget constraint. Each household i provides a different type of labour. Households seek to maximise the discounted sum of expected utilities with regard to consumption C_t and labour N_t subject to a period-by-period budget constraint. Using a constant relative risk aversion utility function, the representative household's lifetime utility can be written as

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^i (C_t^i, N_t^i) \quad (\text{III.4})$$

where β is the discount factor. Specifically, it is

$$u_t^i = \epsilon_t^U \left(\frac{1}{1-\sigma_c} (C_t^i - h C_{t-1}^i)^{1-\sigma_c} - \frac{\epsilon_t^L}{1+\sigma_l} (N_t^i)^{1+\sigma_l} \right) \quad (\text{III.5})$$

where h represents an external habit formation, ϵ_t^U is a general shock to preferences, ϵ_t^L is a specific shock to labour and σ_c , and σ_l are elasticities of consumption, money, and labour. Households maximise their utility due to the intertemporal budget constraint

$$\begin{aligned} & \frac{W_t^i}{P_t} N_t^i + R_t^k Z_t^i K_{t-1}^i - a(Z_t^i) K_{t-1}^i - C_t - I_t^i - A_t^i - \frac{B_t^i R_t^{-1} - B_{t-1}^i}{P_t} + \frac{Div_t}{P_t} Equ_{t-1}^i \\ & - \sum_{j=0}^J \left(\frac{V_{t,t+m}^B}{P_t} B_{t,j}^i - \frac{V_{t-1,t+m-1}^B}{P_t} B_{t-1,t+m}^i \right) - \frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t} = 0 \end{aligned} \quad (\text{III.6})$$

where W_t is the nominal wage, Div_t are dividends, and $(R_t^k Z_t^i - a(Z_t^i)) K_{t-1}^i$ is the return on the real capital stock minus capital utilisation costs. Furthermore, B_t^i denotes a one-period bond; $B_{t,j}^n$ denotes an n -period bond with the respective V_t^C its price. Equ_t^i is a share in an equity index with V_t^E its respective value and A_t^i are state-contingent claims, and I_t^i are investments in capital.

Capital is accumulated according to

$$K_t^i = (1 - \delta)K_{t-1}^i + \left(1 - V\left(\frac{I_t^i}{I_{t-1}^i}\right)\right)I_t^i \quad (\text{III.7})$$

where δ is the depreciation rate and $V(\cdot)$ is similarly defined as in Smets and Wouters (2002).

III.2.2. Firms

Domestic Firms

Final goods are supplied by monopolistically competitive firms using a CES function

$$Y_t = \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t}} dj\right)^{\mu_t} \quad (\text{III.8})$$

where Y_t^j is the input of the intermediate good Y_t^j and μ_t is a price elasticity. Final good producers maximise their profits subject to the production function

$$\max \left(P_t Y_t - \int_0^1 P_t^j Y_t^j \right) \quad (\text{III.9})$$

III.2.3. Intermediate Firms

Intermediate goods Y_t^j are produced using a Cobb-Douglas production function

$$Y_t^j = \epsilon_t^F (\tilde{K}_t^j)^\alpha (N_t^j)^{1-\alpha} \quad (\text{III.10})$$

where ϵ_t^F is a technology shock, \tilde{K}_t are capital services, and N_t is the labour input. Firm profits are immediately paid out as dividends

$$\frac{Equ_{t-1}^j Div_t^j}{P_t} = \frac{P_t^j}{P_t} Y_t^j - \frac{W_t}{P_t} N_t^j - R_t^k \tilde{K}_t^j \quad (\text{III.11})$$

Firms minimise their costs with respect to the production technology. Nominal profits of firm j are given by

$$\pi_t^j = \left(\frac{P_t^j}{P_t} - MC_t\right) Y_t^j = \left(\frac{P_t^j}{P_t} - MC_t\right) \left(\frac{P_t}{P_t^j}\right)^{\frac{-\mu_t}{\mu_t-1}} Y_t \quad (\text{III.12})$$

The pricing kernel is derived from the first-order conditions (FOCs) of the households. This gives the pricing kernel for the discount rate $\frac{1}{1+R_t}$.

Each period, a fraction of the firms $(1 - \theta)$ are able to adjust prices, while the remainder follow a rule of thumb. We denote $\pi_t = \frac{P_t}{P_{t-1}}$ and π is the steady state inflation.

We obtain

$$\begin{aligned} P_t &= \left[\theta \left(P_{t-1} \pi_{t-1}^t \pi^{1-\iota} \right)^{\frac{1}{1-\mu_t}} + (1 - \theta) \overline{P}_t^{\frac{1}{1-\mu_t}} \right]^{1-\mu_t} \\ \Leftrightarrow 1 &= \left[\theta \left(\pi_{t-1} \pi_{t-1}^t \pi^{1-\iota} \right)^{\frac{1}{1-\mu_t}} + (1 - \theta) (\overline{P}_t^*)^{\frac{1}{1-\mu_t}} \right]^{1-\mu_t} \end{aligned} \quad (\text{III.13})$$

III.2.4. Wage Setting

Each household supplies labour based on the following labour-bundling function

$$N_t = \left(\int_0^1 (N_t^i)^{\frac{1}{\gamma_n}} \right)^{\gamma_n} \quad (\text{III.14})$$

where γ_n is wage elasticity and $1 \leq \gamma_n < \infty$. Similarly, the demand for labour is given by

$$N_t^i = \left(\frac{W_t^i}{W_t} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_t \quad (\text{III.15})$$

Reflecting the specification of the firms' optimisation problem, they face a random probability $(1 - \theta_h)$ of changing the nominal wage. The reoptimised wage of household i^{th} is \overline{W}_t^i , whereas the unchanged wage is adjusted by $W_{t+1}^i = W_t^i \pi_t^{\iota_h} \pi^{1-\iota_h}$.

Households then maximise their optimal wage subject to the demand for labour and the budget constraint.

III.2.5. The Financial Sector

The literature contains several approaches for including a financial sector in a macroeconomic model. Gertler, Kiyotaki and Queralto (2012) apply a micro-based model and incorporate a banking sector and financial frictions. However, as our focus here is on spillovers from the asset markets to the real economy, intermediaries are of limited interest to us. Brunnermeier and Sannikov (2012) construct a macroeconomic model with an emphasis on variations in risk preferences and the degree of information across households and financial experts, but since they do not model real economic effects, their framework is not suitable for our study of financial and macroeconomic spillovers. Therefore, we follow Bekaert, Cho and Moreno (2010) and Paoli, Scott and Weeken (2010b) and model bond and asset yields first in discrete

time, after which we switch to continuous time. Moreover, we extend the NK framework of Paoli, Scott and Weeken (2010b) by defining different term structures and rigidities.

As long as there are no frictions, our model exhibits the classic equity and term premia puzzle. As demonstrated by Campbell and Cochrane (1999) in the context of endowment economies, consumption habits can be used to solve this puzzle. When switching off capital adjustment costs, we confirm the previous result of Boldrin, Christiano and Fisher (2001) that, in a production economy, consumption habits by themselves are not sufficient solve the puzzle. In fact, consumer-investors can eat into capital and, thereby, change production plans. In other words, we need to ensure that households do not merely dislike consumption volatility, they have to be prevented from doing something about it; capital adjustment costs are a useful modelling device for achieving this.

The presence of state-contingent claims implies that we can price all financial assets in the economy based on no-arbitrage arguments. The price of a zero-coupon bond is therefore given by the FOCs. We follow Binsbergen, Fernandez-Villaverde, Koijen and Rubio-Ramírez (2012) and Paoli, Scott and Weeken (2010b) and model the term structure recursively

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{III.16})$$

Tobin's Q is given by $q_t^i = \frac{\varphi_t^i}{\lambda_t^i}$ in

$$q_t^i = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(R_t^k Z_t^i - a(Z_t^i) \right) + q_{t+1}^i (1 - \delta) \right) \quad (\text{III.17})$$

A real zero-coupon bond returns one unit of consumption at maturity, and the remaining time is j . For $j = 1$, it is

$$-\lambda_t \frac{V_{t,1}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,0}}{P_{t+1}} \right] \quad (\text{III.18})$$

$$\Leftrightarrow V_{t,1}^B = E_t \left[-\beta V_{t+1,0} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{III.19})$$

$V_{t+1,1}$ is the price of a real bond of original maturity $m = 2$ with one period left. Assuming no arbitrage, this price equals the price of a $m = 1$ bond issued next period. Bond prices thus can be defined recursively (using $SDF_t = \beta \frac{\lambda_{t+1}}{\lambda_t}$)

$$V_{t,t+m}^B = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} V_{t+1,t+m-1}^B \frac{P_t}{P_{t+1}} \right] \quad (\text{III.20})$$

$$= E_t (SDF_{t+1} \pi_{t+1} V_{t+1,t+m-1}^B) \quad (\text{III.21})$$

Assuming $V_{t,1} = 1$ in terms of one unit of consumption and applying recursion, we obtain

$$V_{t,t+m}^B = E_t ((SDF_{t+1} \pi_{t+1})^j) \quad (\text{III.22})$$

Real yields are then given by

$$R_{t+1,t+m}^B = (V_{t,t+m}^B)^{-\frac{1}{j}} \quad (\text{III.23})$$

Regarding the stocks, we derive

$$1 = E_t \left[-\beta \frac{P_t}{P_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \frac{V_t^E + Div_{t+1}}{V_t^E} \right]$$

implying a real return of

$$R_{t+1}^E = \frac{V_t^E + Div_t}{V_t^E} \frac{P_t}{P_{t+1}}$$

The model reconciles the non-stationary behaviour of consumption found in the macro literature with the assumption of stationary interest rates in the finance literature. Andreasen (2012), Andreasen (2010) and Wu (2006) show that this specification equals standard finance models such as those of Dai and Singleton (2000), Duffie and Kan (1996) and Duffie, Pan and Singleton (2000) .

III.2.6. The Monetary Reaction Function

In line with Ball (1998), Justiniano, Primiceri and Tambalotti (2010), Leitemo and Soderstrom (2005), Lubik and Schorfheide (2007), Lubik and Smets (2005), Smets and Wouters (2007), Svensson (2000a) and Taylor (1993), we apply a standard Taylor rule.

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\pi_t \pi}{\pi_{t-1}} \right)^{\psi_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\psi_Y} \right]^{1-\rho_{E^*}} \eta_{mp,t} \quad (\text{III.24})$$

where $\eta_{mp,t}$ is a monetary policy shock.

$$\log(\eta_{mp,t}) = \rho_{mp,t} \log(\eta_{mp,t-1}) + \epsilon_{mp,t} \quad (\text{III.25})$$

where $\epsilon_{mp,t}$ is *i.i.d.* $N(0, \sigma_{mp}^2)$

III.2.7. Market Clearing

We treat equities and bonds as financial instruments and assign them to a new sector, the financial market. A shortcoming of this sector is that it has no purpose other than an allocative one. However, in building a bridge between finance and macroeconomic research, we model financial instruments stochastically and thus the solely allocational purpose of the financial market sector is appropriate for our analysis. In principle, introducing a banking sector or entrepreneurs would easily overcome this shortcoming. However, for the sake of simplicity, we adhere to the solely allocative purpose. Thus, the market clearing condition is

$$Y_t = C_t + I_t + FM + a(Z_t)K_{t-1} \quad (\text{III.26})$$

where FM is the financial market sector.

III.3. Linearisation and Continuous Time

III.3.1. Linearisation

Equities and bonds must be linearised at least up to the second order. Indeed, Andreasen (2012) propose linearising to the third order so as to capture the time-varying effects of the term structure. Normal linearisation would yield risk-neutral market participants, implying similar prices for all assets. We overcome this dilemma and follow Paoli, Scott and Weeken (2010b) and Wu (2006) by assuming $\ln(SDF_{t+1}\pi) = \alpha_0 + \alpha_1 s_t + \alpha_2 \epsilon_{t+1}$, where s_t are the state variables. $\frac{P_t}{P_{t+1}} = \pi_{t+1}$ is the inflation rate. We then apply a third-order approximation for the relevant yields. We linearise the economy using perturbation.

Following Wu (2006), we use the approach of Jermann (1998) and log-linearise around the non-stochastic steady state and solve the resulting system of linear difference equations. The issue of non-stationarity is tackled by rescaling all variables. We assume that the model solution is given by variables

z_t such that

$$z_t = \mu_z + \Sigma_z s_t \quad (\text{III.27})$$

where s_t is an AR(1) process. In line with Binsbergen, Fernandez-Villaverde, Koijen and Rubio-Ramírez (2012), the bond equation has the following form

$$\begin{aligned} \ln(VB_{t,m}) = & E_t (\ln(SDF_{t+1}) + \ln(VB_{t+1,m-1})) \\ & + \frac{1}{2} \text{var} (\ln(SDF_{t+1}) + \ln(VB_{t+1,m-1})) \\ & + \frac{1}{6} \text{skew} (\ln(SDF_{t+1}) + \ln(VB_{t+1,m-1})) \end{aligned} \quad (\text{III.28})$$

Equation (III.28) holds exactly when the conditional distribution of the bond price VB and the stochastic discount factor SDF are joint log-normal, but it still holds approximately if this is not the case (Wu 2006). Our model falls within the class of affine term structure models, since the logarithm of the bond prices is a system of linear (or affine) functions of the state variables. Our model is somewhat similar to standard finance models such as Dai and Singleton (2000), Duffie and Kan (1996) and Duffie, Pan and Singleton (2000), but it includes a macroeconomic base and therefore bridges the gap between finance and macroeconomic research.

III.3.2. Continuous-Time Modelling

One disadvantage of NK models is the absence of an explicit solution for the baseline model. A standard response to this problem is to linearise the model around the steady state. However, this causes a loss of information. Term structure models must be linearised at least up to the second order, which aggravates the loss of information and, furthermore, there is no longer an explicit solution to the model.

We propose a different approach. Reflecting work by Asada, Chen, Chiarella and Flaschel (2006) and Chen, Chiarella, Flaschel and Hung (2006), we switch to a continuous-time framework by using difference equations transformed to differential equations. NK models are based on difference equations such as, for example, the consumption equation, which depends on the actual and prior values. Using time-scale calculus, we can then transform these equations into differential equations. To explicitly account for shocks, we propose stochastic differential equations. In contrast to Fernández-Villaverde, Posch and Rubio-Ramírez (2011), who works only within the continuous-time domain, we first derive the discrete model. This allows us to directly link our approach to standard macroeconomic theory and compare core results derived using the continuous-time models with those from the discrete-time model. Time-scale calculus makes it possible to switch from discrete time to continuous time. Time-scale

calculus is a formal unification of the theory of difference equations with that of differential equations. A general overview is provided by Agarwal, Bohner, O'Regan and Peterson (2002) and Turnovsky (2000); the theoretical basis for applying this concept to stochastic differential equations is given by Sanyal (2008).

We augment the standard representation of stocks and bonds (see Merton (1969)) to reflect our assumptions of simultaneity and highly interacted markets by incorporating the monetary policy rate and the log-linearised stock price into the bond yield equation. Similarly, we add the bond yield and the monetary policy rate to the stock price equation. Since we consider stock prices to be an important link between the real and the monetary economy, we add the output gap to the stock market equation. In the price equations for stocks and bonds, we account for the future stream of dividend payments by adding the inflation rate positively and the (nominal) interest rate negatively. This approach accounts for the Fisher effect and, hence, stock prices rise with increasing inflation. Including the output gap in the stock market equation is in line with Cooper and Priestley (2009) and Vivian and Wohar (2013). A general approach to accounting for macroeconomic factors in stock returns is provided by Pesaran and Timmermann (1995). We make no explicit assumptions about how bond and stock markets influence each other. When bond yields are inside a small interest rate band (of realistic size), the correlation between bonds yields and stock yields (and equity prices) is mainly positive. However, when yields are outside this band, the correlation is mainly negative. In line with the relevant finance literature (Barndorff-Nielsen and Shephard 2001; Fama 1965a; Malkiel and Fama 1970), we model stock prices as geometric Brownian motion processes and bond yields as Ornstein-Uhlenbeck processes. Since disturbances are specified as AR(1) processes, we can interpret the shocks as standard Brownian motions and the macroeconomic variables as system of stochastic differential equations.

$$dS = (S_t((r - \lambda\mu) + \rho_b b_t + \rho_y y_t + \rho_\pi \pi_t))dt + \sqrt{V_t}dW_S(t) + \sum_{i=1}^{dN_t} J(Q_i) \quad (\text{III.29})$$

$$dV_t = \kappa(\theta - V_t)dt + \sigma \sqrt{V_t}dW_V(t)$$

$$db_t = (\gamma_b b_t + \gamma_S S_t + \gamma_y y_t - \gamma_i(R_t - \pi_t))dt + \sigma_b dW_b(t) \quad (\text{III.30})$$

where $J(Q)$ is the Poisson jump amplitude, Q is an underlying Poisson amplitude mark process ($Q = \ln(J(Q)+1)$), and $N(t)$ is the standard Poisson jump-counting process with jump density λ and $E(dN(t)) = \lambda dt = \text{Var}(dN(t))$. dW_S and dW_V denote Brownian motions.

Stability is an important aspect of differential equations. We employ Lyapunov techniques to analyse the stability of our model. For a thorough discussion of these techniques, see (Khasminskii 2012). We

apply the following Lyapunov function:

$$\|x\|_2^2 = \left(\sqrt{\sum |x_i|^2} \right)^2 \quad (\text{III.31})$$

where $\|\cdot\|_2$ denotes the Euclidean norm. Since the zero solution is only locally stable, there is no global stable rest point. However, even though there are only parameter-dependent partial solutions, these are 'almost' stable. In the following section, we analyse stability for each set of parameters we derive.

Because our focus is on business cycles, we concentrate our dynamic analysis on short-run adjustments. Within this timeframe, there is no guarantee that the variables will actually return to their starting values.

III.4. Comparison of Discrete- and Continuous-Time Results in the Standard Model

To show that our continuous-time model encompasses standard macroeconomic results derived in discrete-time models, we compare both types of specification. As there is no explicit analytical solution, we compare the respective impulse response functions. For the parameters, we choose standard values from the literature (see column 2 of Table III.1).

Calibration of the household and firm side is standard. Elasticities of substitution regarding investments and consumption $(\eta_d^c, \eta_d^i, \eta_f^c, \eta_f^i)$ vary between 1.30 and 1.50 (Fernández-Villaverde 2010). The household's utility function is similar to the one employed by Smets and Wouters (2007). The elasticity for substitution of consumption σ is 1.20; the elasticity of substitution for labour σ_l is 1.25. On the supply side, we assume standard Calvo-pricing parameters as in Smets and Wouters (ibid.). The Calvo parameters for prices θ and wages θ_h are 0.75. We use monetary policy parameters similar to those of Adolfson, Laseen, Linde and Svensson (2011) and Lindé (2005). The inflation parameter ψ_π is 1.20, reflecting our assumption that a central bank's chief goal is disinflation stability. Further details can be found in the cited literature.

We analyse monetary policy shocks and shocks to the financial market instruments (bonds and stocks). In general, we find that the main difference between continuous- and discrete-time adjustment is the high number of small fluctuations within the continuous-time framework. This reveals that the adjustment process to the steady state is somewhat different from what even third-order approximation in discrete time can capture. Our main goal is to analyse monetary policy and financial market behaviour and we therefore concentrate on shocks to monetary policy and financial variables.

Figure III.2 shows the impulse response functions after a contractionary monetary policy shock. For

both specifications, the shock causes a decrease in output and inflation. However, the additional nonlinearities and the better-specified interaction with the financial market reveal more fluctuations in the continuous-time compared to the discrete-time scenario. On the one hand, the discrete-time scenario looks like a text-book economy, where monetary policy is able to steer the adjustment in a way such that there is no overshooting. The exception is investment, which shows no tendency to return to the baseline within our observation window. In the continuous-time case, on the other hand, the recession is followed by a boom and only then does the economy return to the baseline. Stabilisation policy as modelled by the Taylor rule leads to several interventions by the central bank, as financial market fluctuations which were triggered by monetary policy, feed back into the real economy and contribute to the resulting business cycle. Reflecting these adjustments, bond prices, inflation, and the stock market are also subject to more fluctuation. Overall, we find a much more realistic picture of the effects of a monetary policy shock, i.e., one that is more in line with the stylised facts derived from VAR models (see Bernanke, Boivin and Elias (2005) and Christiano, Eichenbaum and Evans (2005)).

Figure III.4 studies the response after a negative bond price shock. A negative bond price shock can be interpreted as an increase in market participants' risk aversion. In both models, financial and real variables show a cyclical adjustment pattern back to equilibrium. There are also clear spillovers between the two financial markets and to the real economy. However, the continuous-time model is characterised by much richer dynamics than is the discrete-time model, for instance, the decline in GDP is smooth rather than abrupt as in the discrete-time scenario. Thus, we can actually generate realistic-looking business cycles in the real economy via financial market shocks. This is a very clear illustration of how important financial market shocks are to the macroeconomy.

Figure III.6 shows the results of a negative stock price shock. Here, the differences between the models are even more marked. Whereas in the discrete-time model, the stock market crash causes almost no decline in output or investments and recovers fast, the shock causes implausible dynamic adjustments of the other variables in the system, e.g. increasing GDP and investments, shock causes a recession followed by a boom in continuous time due to increased investment opportunities. Furthermore, the negative stock price shock leads to a cyclical bond market adjustment in the continuous-time model. So again the continuous-time model provides plausible interactions between the real economy and the financial markets. We argue that the more realistic dynamics illustrate the effectiveness of using findings from financial literature in macroeconomic models. As financial markets are better simulated and integrated into the system of equations, a stock market shock is transmitted more realistically to other parts of the economy

To summarise, all simulations suggest that the continuous-time model captures business cycles better

than do standard DSGE models. The improvement is especially noteworthy in the case of the financial variables, where we observe a full adjustment process instead of immediate reactions.

III.5. Employing Empirically Estimated Parameters: The United States

We now test our model with real-world data using Markov Chain Monte Carlo (MCMC) methods, a Bayesian estimation technique (approximate Bayesian computation; see Beaumont, Zhang and Balding (2002)), particularly suited to estimating stochastic differential equations. In principle, the technique allows estimating even more complex models, such as multi-country models with financial markets. Here, reflecting the assumption of a closed economy made in the theoretical analysis, we estimate the model using US data. We then compare the theoretical with the empirical impulse response functions. Since estimating a nonlinear model is difficult, two inputs are crucial for obtaining plausible results through MCMC estimations: first, the choice of priors and, second, the choice of initial values. Our choice of prior distributions for New Keynesian models is similar to that of, among others, Smets and Wouters (2007), Negro, Schorfheide, Smets and Wouters (2007) or Lindé (2005). We follow Kimmel (2007) and Jones (2003) in choosing normal distributions for the variance of bond and stock price shocks. An overview of the priors is given in columns 3 to 5 of Table III.1.

We apply the MCMC estimation to the United States. Data are from the Federal Reserve Bank of St. Louis and the US Bureau of Labor Statistics. We employ quarterly data from 1957:Q1 to 2013:Q4. We use a bandpass filter (as suggested by Christiano and Fitzgerald (1999)) to eliminate noise from the variables and employ a Hodrick Prescott filter as a robustness check. The inflation series is constructed by the GDP deflator. We use the S&P 500 stock market index to capture stock prices.

Table III.1 contains the results of the MCMC estimations. The posterior values for the means and variances are set out in columns 6 and 7. Note that these parameters are in line with previous findings, such as those of Smets and Wouters (2002, 2007). This suggests that our approach is a tractable way of solving and estimating nonlinear DSGE models. Figure III.7 shows impulse response functions following an contractionary monetary policy shock. The results are similar to those found in the extant literature (e.g. Justiniano, Primiceri and Tambalotti (2010)). Our findings are also in line with the calibrated continuous-time model outlined above. However, we observe only negligible reactions by the investments in the estimation if the policy rate is cut, but stronger reactions if the policy rate is later increased.

III.6. Conclusions

In this paper, we study the relationship between macroeconomic and financial variables in the framework of a continuous-time New Keynesian DSGE model. Hence, method-wise, we provide another way of analysing nonlinear New Keynesian models without linearising, a particularly important advantage when it comes to DSGE models with term structure as linearisation can seriously distort the results. Usually, therefore, third-order perturbation methods are called for but solutions are difficult to find with these methods and estimations are even more difficult to implement. In contrast, stochastic differential equations can be used to both implement and estimate these models. Moreover, the continuous-time approach reveals greater dynamic fluctuations compared to the standard linearised models. By including financial market term structure in continuous time, we can implement bonds, stocks, call prices, and the like in our model, for instance, in the form of the Vasicek model, jump-diffusion processes, or Black Scholes calls. We thus combine classic research from the field of finance with macroeconomic models. In addition, we can interact the financial markets and account for financial market integration. Model stability is proven by applying a Lyapunov function. Thus, in our analysis, we combine New Keynesian macroeconomic analysis, classic finance research, and standard mathematical procedures.

Our main research quest is to understand the effects of financial market shocks and monetary policy in a theoretical framework that allows for feedback between financial markets and the real economy. In line with economic theory and empirical evidence, we begin with a steady-state solution. We simulate financial market reaction to monetary policy and monetary policy reaction to financial turmoil in the context of a standard Taylor rule. For our simulations, the model parameters are based on empirical findings from work on the Taylor rule, the New Keynesian Phillips curve, and the IS curve; our financial equations rely on findings by Merton (1970) and Black and Scholes (1973b). However, we extend all financial equations by accounting for spillover effects from monetary variables to real variables and vice versa. We analyse monetary shocks as well as financial market shocks and follow their transmission to the real economy.

In general, we find that the scenarios based on continuous-time models exhibit much more realistic adjustment patterns than those based on discrete-time models. First, a contractionary monetary policy shock has negative effects on output and inflation as well as repercussions for both financial markets. The financial market fluctuations cause spillovers to the real economy and induce further adjustments in monetary policy. As a result, we find that monetary policy shocks cause adjustments in real and financial variables. Second, the responses after a negative bond price shock reveal a cyclical adjustment pattern back to equilibrium. Hence, using financial market shocks, we can generate realistic-looking business cycles in output and inflation. The continuous-time models also provide highly satisfactory results in the

case of a simulated stock market crash; the observed adjustments are far more realistic than those seen using discrete-time models.

We then test our theoretical model with real-world data from the United States. Employing quarterly data over the period 1957:Q1 to 2013:Q4, we use Bayesian estimation techniques to derive the model's parameters. The simulation results support those from the purely theoretically parameterised continuous-time model. We find spillover effects from monetary policy to financial markets and from financial markets to monetary policy.

Our study discovers some useful ways of implementing very complicated nonlinear DSGE models that will make it easier to study financial markets in both closed and open economies and facilitate the estimation of nonlinear models using different Bayesian methods. However, we analysed only a closed economy and did not account for international spillovers. Hence, there are various ways of productively extending our analysis. First, looking at an open economy with monetary spillover effects might provide additional insight. The model also permits comparing different monetary policy reaction functions; for example, we could include a financial market indicator in the Taylor rule. Furthermore, we did not account for a fiscal authority. Thus, extending the model by including government fiscal policy targets could be of interest, especially since we observe that bond markets hardly react to monetary policy. The hypothesis that bond markets are relatively more driven by fiscal policy could be tested with a differently specified model. Moreover, the model could be expanded to account for an even greater number of financial markets. The inclusion of the Black-Scholes formula or advanced option-pricing techniques would permit analysing an almost complete model of the financial system. Finally, in light of the recent financial and sovereign debt crises, a specific analysis of crises could be interesting. As outlined above, the model is capable of measuring the impact of financial market bubbles in a two-economy framework. Including jump-diffusion processes would add another source of financial market volatility and could help explain times of crisis.

III.7. Appendix

III.7.1. Technical Appendix

The Baseline Model

Households

We assume that the economy is inhabited by a continuum of consumers $i \in [0, 1]$. First, we consider a consumption index, such as that of Dixit and Stiglitz (1977), $C_t(P_t)$ which consists of goods c_t^j produced by firm j . η_c is the elasticity of demand. Similarly, we define a production price index P_t , using p_t^j .

$$C_t = \left[\int_0^1 (C_t^j)^{\frac{\eta_c-1}{\eta_c}} dj \right]^{\frac{\eta_c}{\eta_c-1}} \quad (\text{III.32})$$

Accordingly, the aggregate price index (the CPI) is given by

$$P_t = \left[\int_0^1 (P_t^j)^{1-\eta_c} dj \right]^{\frac{1}{1-\eta_c}} \quad (\text{III.33})$$

Consumption is maximised subject to $\int_0^1 (P_t^j C_t^j) dj = Z_t$, where Z_t are expenditures.

$$C_t^j = \left(\frac{P_t^j}{P_t} \right)^{-\eta_c} C_t \quad (\text{III.34})$$

There is a continuum of households i which live infinitely. Households seek to maximise the discounted sum of expected utilities with regard to consumption C_t and labour N_t subject to a period-by-period budget constraint. Using a constant relative risk aversion utility function (CRRA), the representative household's lifetime utility can be written as

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^i(C_t^i, N_t^i) \quad (\text{III.35})$$

where β is the discount factor and E_0 the expected value at time 0. In particular it is

$$u_t^i = \epsilon_t^U \left(\frac{1}{1-\sigma_c} (C_t^i - h C_{t-1}^i)^{1-\sigma_c} - \frac{\epsilon_t^L}{1+\sigma_l} (N_t^i)^{1+\sigma_l} \right) \quad (\text{III.36})$$

where h represents an external habit formation, ϵ_t^U is a general shock to preferences, ϵ_t^L is a specific shocks to labour and σ_c , and σ_l are elasticities of consumption, money and labour. Households

maximise their utility due to the intertemporal budget constraint

$$\begin{aligned}
 & \frac{W_t^i}{P_t} N_t^i + R_t^k Z_t^i K_{t-1}^i - a(Z_t^i) K_{t-1}^i \\
 & - \frac{B_t^i R_t^{-1} - B_{t-1}^i}{P_t} - \sum_{j=0}^J \left(\frac{V_{t,t+m}^B}{P_t} B_{t,j}^i - \frac{V_{t-1,t+m-1}^B}{P_t} B_{t-1,t+m}^i \right) \\
 & - \frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t} + \frac{Div_t}{P_t} Equ_{t-1}^i - C_t - I_t^i - A_t^i = 0
 \end{aligned} \tag{III.37}$$

where W_t is the nominal wage, Div_t are dividends, $(R_t^k Z_t^i - a(Z_t^i)) K_{t-1}^i$ is the return on the real capital stock minus capital utilisation costs. Furthermore, B_t^i denote a one-period bonds, $B_{t,j}^i$ denotes a n -period bond with respective V_t^C its price. Equ_t^i is a share in an equity index and with respective value V_t^E and A_t^i are stage-contingent claims, I_t^i are investments.

Furthermore, households are subject to capital accumulation

$$K_t^i = (1 - \delta) K_{t-1}^i + \left(1 - V \left(\frac{I_t^i}{I_{t-1}^i} \right) \right) I_t^i \tag{III.38}$$

We obtain the first order conditions (where E_t denotes the expected value at time t)

$$C_t^i : \quad \epsilon_t^U (C_t^i - h_t C_{t-1}^i)^{-\sigma_c} - \beta h E_t [\epsilon_{t+1}^U (C_{t+1}^i - h C_t^i)^{-\sigma_c}] - \lambda_t = 0 \tag{III.39}$$

$$N_t^i : \quad \epsilon_t^U \epsilon_t^L (N_t^i)^{\sigma_L} - \lambda_t \frac{W_t^i}{P_t} = 0 \tag{III.40}$$

$$B_t^i : \quad -\frac{\lambda_t}{R_t P_t} + \beta E_t \left[\frac{\lambda_{t+1}}{P_{t+1}} \right] = 0 \tag{III.41}$$

$$Z_t^i : \quad R_t^k - a'(Z_t^i) = 0 \tag{III.42}$$

$$K_t^i : \quad \beta E_t [\lambda_{t+1} (R_t^k Z_t^i - a(Z_t^i))] - \varphi_t + \beta E_t [\varphi_{t+1} (1 - \delta)] = 0 \tag{III.43}$$

$$I_t^i : \quad -\lambda_t + \varphi_t \left(1 - V \left(\frac{I_t^i}{I_{t-1}^i} \right) \right) - \varphi_t \left(\frac{I_t^i}{I_{t-1}^i} \right) V' \left(\frac{I_t^i}{I_{t-1}^i} \right) + \beta E_t \left(\varphi_{t+1} \left(\frac{I_{t+1}^i}{I_t^i} \right)^2 V' \left(\frac{I_{t+1}^i}{I_t^i} \right) \right) = 0 \tag{III.44}$$

$$Equ_t^i : \quad -\frac{\lambda_t V_t^E}{P_t} + \beta \left(E \left(\lambda_{t+1} \frac{V_{t+1}^E + Div_{t+1}^i}{P_{t+1}} \right) \right) = 0 \tag{III.45}$$

$$B_{t,t+m}^i : \quad -\lambda_t \frac{V_{t,t+m}^B}{P_t} + E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,t+m-1}^B}{P_{t+1}} \right] = 0 \tag{III.46}$$

Following Fernández-Villaverde (2010) we assume the capital adjustment costs a to be like

$$a(u) := \gamma_1 (u - 1) + \gamma_2 (u - 1)^2$$

the investment adjustment cost function is

$$S\left(\frac{x_t}{x_{t-1}}\right) = \frac{\kappa}{2} \left(\frac{x_t}{x_{t-1}} - \Lambda_x\right)^2$$

in our case $x_t = I_t^i$ and Λ_x is the growth rate of investment δ .

Firms

Domestic Firms

Final goods are derived by monopolistic competition using a CES function

$$Y_t = \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t}} dj \right)^{\mu_t} \quad (\text{III.47})$$

where Y_t^j is the input of the intermediate good Y_t^j and μ_t is a price elasticity. Final good producers maximise their profits subject to the production function

$$\max \left(P_t Y_t - \int_0^1 P_t^j Y_t^j \right) \quad (\text{III.48})$$

The first order conditions are given by

$$0 = -P_t^j + P_t \mu_t \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t}} dj \right)^{\mu_t - 1} \left(\frac{1}{\mu_t} (Y_t^j)^{\frac{1 - \mu_t}{\mu_t}} \right) \quad (\text{III.49})$$

$$\Leftrightarrow 0 = -P_t^j + P_t \left(\left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t}} dj \right)^{\mu_t} \right)^{\frac{\mu_t - 1}{\mu_t}} (Y_t^j)^{\frac{1 - \mu_t}{\mu_t}} \quad (\text{III.50})$$

$$\Leftrightarrow \frac{P_t^j}{P_t} = Y_t^{\frac{\mu_t - 1}{\mu_t}} (Y_t^j)^{-\frac{\mu_t - 1}{\mu_t}} \quad (\text{III.51})$$

$$\Leftrightarrow Y_t^j = \left(\frac{P_t}{P_t^j} \right)^{\frac{\mu_t}{\mu_t - 1}} Y_t \quad (\text{III.52})$$

Integrating III.52 into III.9 we obtain

$$Y_t = \left(\int_0^1 \left(\left(\frac{P_t}{P_t^j} \right)^{\frac{\mu_t}{\mu_t-1}} Y_t \right)^{\frac{1}{\mu_t}} dj \right)^{\mu_t} \quad (\text{III.53})$$

$$\Leftrightarrow Y_t = \left(\int_0^1 \left(\frac{P_t}{P_t^j} \right)^{\frac{1}{\mu_t-1}} Y_t^{\frac{1}{\mu_t}} dj \right)^{\mu_t} \quad (\text{III.54})$$

$$\Leftrightarrow Y_t = Y_t \left(\int_0^1 \left(\frac{P_t}{P_t^j} \right)^{\frac{1}{\mu_t}} dj \right)^{\mu_t} \quad (\text{III.55})$$

$$\Leftrightarrow 1 = P_t^{\frac{\mu_t}{\mu_t-1}} \left(\int_0^1 (P_t^j)^{-\frac{1}{\mu_t-1}} dj \right)^{\mu_t} \quad (\text{III.56})$$

$$\Leftrightarrow P_t^{-\frac{\mu_t}{\mu_t-1}} = \left(\int_0^1 (P_t^j)^{\frac{1}{1-\mu_t}} dj \right)^{\mu_t} \quad (\text{III.57})$$

$$\Leftrightarrow P_t = \left(\int_0^1 (P_t^j)^{\frac{1}{1-\mu_t}} dj \right)^{1-\mu_t} \quad (\text{III.58})$$

Intermediate Firms

The intermediate good Y_t^j is produced using a Cobb-Douglas production function

$$Y_t^j = z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{1-\alpha} \quad (\text{III.59})$$

where Φ_t is the total factor productivity, ϵ_t^F is a technology shock, \tilde{K}_t are capital services, N_t is the labour input. Firms profits are immediately paid out as dividends

$$\frac{Equ_{t-1}^j Div_t^j}{P_t} = \frac{P_t^j}{P_t} Y_t^j - \frac{W_t}{P_t} N_t^j - R_t^k \tilde{K}_t^j \quad (\text{III.60})$$

Firms minimise their costs with respect to the production technology

$$\tilde{K}_t^j : \quad R_t^k - \Gamma_t \alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha} \quad (\text{III.61})$$

$$\Leftrightarrow \frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}} = \Gamma_t \quad (\text{III.62})$$

$$N_t^j : \quad \frac{W_t}{P_t} - \Gamma_t (1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha} = 0 \quad (\text{III.63})$$

$$\Leftrightarrow \frac{W_t}{P_t (1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha}} = \Gamma_t \quad (\text{III.64})$$

This implies

$$\frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}} = \frac{W_t}{P_t (1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha}} \quad (\text{III.65})$$

$$\Leftrightarrow \frac{R_t^k}{W_t} = \frac{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}}{P_t (1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha}} \quad (\text{III.66})$$

$$\Leftrightarrow \frac{W_t}{R_t^k} = \frac{P_t (1-\alpha) \tilde{K}_t^j}{\alpha N_t^j} \quad (\text{III.67})$$

$$\Leftrightarrow \tilde{K}_t^j = \frac{\alpha}{1-\alpha} \frac{W_t}{P_t R_t^k} N_t^j \quad (\text{III.68})$$

We interpret the Lagrangian parameters as marginal costs

$$\frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t \left(\frac{\alpha}{1-\alpha} \frac{W_t}{P_t R_t^k} N_t^j \right)^{\alpha-1} (N_t^j)^{1-\alpha}} = MC_t \quad (\text{III.69})$$

$$\Leftrightarrow \frac{(R_t^k)^\alpha \left(\frac{W_t}{P_t} \right)^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha} z_t^{1-\alpha} \epsilon_t^F \Phi_t} = MC_t \quad (\text{III.70})$$

Nominal profits for firm j are therefore given by

$$\pi_t^j = \left(\frac{P_t^j}{P_t} - MC_t \right) Y_t^j = \left(\frac{P_t^j}{P_t} - MC_t \right) \left(\frac{P_t}{P_t^j} \right)^{\frac{-\mu_t}{\mu_t-1}} Y_t \quad (\text{III.71})$$

The pricing kernel is derived from the FOCs of the households

$$\frac{\lambda_t}{P_t} = \beta E_t \left(\frac{(1+R_t) \lambda_{t+1}}{P_{t+1}} \right) \quad (\text{III.72})$$

$$\Leftrightarrow \beta E_t (1+R_t) = E_t \frac{P_{t+1}}{\lambda_{t+1}} \frac{\lambda_t}{P_t} \quad (\text{III.73})$$

This gives the pricing kernel for the discount rate $\frac{1}{1+R_t}$.

Each period a fraction of firms $(1-\theta)$ is able to adjust prices, the remaining fraction follows a rule of thumb. We denote $\pi_t = \frac{P_t}{P_{t-1}}$ and π is the steady state inflation.

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\frac{\overline{P}_t^j}{P_{t+s}} \prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota}) - MC_{t+s} \right) Y_{t+s}^j \quad (\text{III.74})$$

$$s.t. \left(\frac{\overline{P}_t^j \prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota})}{P_{t+s}} \right)^{-\frac{\mu_{t+s}}{\mu_{t+s}-1}} Y_{t+s} = Y_{t+s}^j \quad (\text{III.75})$$

it is $-\frac{\mu_{t+s}}{\mu_{t+s}-1} = \delta$

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\left(\frac{1}{P_{t+s}} \overline{P}_t^j \prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota}) \right)^{\delta+1} \frac{Y_{t+s}}{P_{t+s}^{\delta}} - MC_{t+s} \left(\overline{P}_t^j \prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota}) \right)^{\delta} \frac{Y_{t+s}}{P_{t+s}^{\delta}} \right) \quad (\text{III.76})$$

it is

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\left(\frac{1}{P_{t+s}} \right)^{\delta} \overline{P}_t^j (\delta+1) \left(\prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota}) \right)^{\delta+1} \frac{Y_{t+s}}{P_{t+s}^{\delta}} \right. \\ \left. - E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(MC_{t+s} \delta \overline{P}_t^j (\delta-1) \left(\prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota}) \right)^{\delta} \frac{Y_{t+s}}{P_{t+s}^{\delta}} \right) = 0 \quad (\text{III.77})$$

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\left(\overline{P}_t^j \right)^{\delta} \left(\prod_{l=1}^s \frac{1}{\pi_{t+l}} \right)^{1+\delta} (1+\delta) \left(\prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota}) \right)^{\delta+1} Y_{t+s} \right) \\ - E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\delta MC_{t+s} \left(\overline{P}_t^j \right)^{\delta-1} \left(\prod_{l=1}^s \frac{1}{\pi_{t+l}} \right)^{\delta} \left(\prod_{l=1}^s (\pi_{t+l-1}^t \pi^{1-\iota}) \right)^{\delta} Y_{t+s} \right) = 0 \quad (\text{III.78})$$

From III.58 we get

$$P_t = \left[\theta \left(P_{t-1} \pi_{t-1}^t \pi^{1-\iota} \right)^{\frac{1}{1-\mu_t}} + (1-\theta) \overline{P}_t^{\frac{1}{1-\mu_t}} \right]^{1-\mu_t} \quad (\text{III.79})$$

$$\Leftrightarrow 1 = \left[\theta \left(\pi_{t-1} \pi_{t-1}^t \pi^{1-\iota} \right)^{\frac{1}{1-\mu_t}} + (1-\theta) (\overline{P}_t^*)^{\frac{1}{1-\mu_t}} \right]^{1-\mu_t} \quad (\text{III.80})$$

Wage Setting

Each household sells his labour due to the labour bundling function

$$N_t = \left(\int_0^1 \left(N_t^i \right)^{\frac{1}{\gamma_n}} \right)^{\gamma_n} \quad (\text{III.81})$$

where γ_n is the wage elasticity and $1 \leq \gamma_n < \infty$. Similarly, the demand for labour is given by

$$N_t^i = \left(\frac{W_t^i}{W_t} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_t \quad (\text{III.82})$$

Similarly to the firm's problem households face a random probability $1 - \theta_h$ of changing nominal wage. The i^{th} households reoptimised wage is \overline{W}_t^i , whereas the unchanged wage is given by $W_{t+1}^i = W_t^i \pi_t^{\iota_h} \pi^{1-\iota_h}$, Households then maximise their optimal wage subject to the demand for labour and the budget constraint.

$$N_{t+s}^i = \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h})}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \quad (\text{III.83})$$

The Langrangian function is

$$E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s \left(-\frac{\epsilon_{t+s}^L}{1 + \sigma_l} (N_{t+s}^i)^{1+\sigma_l} + \lambda_{t+s} \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h})}{P_{t+s}} N_{t+s} \right) \right) \quad (\text{III.84})$$

$$+ E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s \left(\lambda_{t+s}^b \left(N_t^i - \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h})}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \right) \right) \quad (\text{III.85})$$

FOCs

$$\overline{W}_t^i : E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s \left(\lambda_{t+s} \frac{\prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h})}{P_{t+s}} N_{t+s} \right) \quad (\text{III.86})$$

$$- E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s \left(\epsilon_{t+s}^L \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h})}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \right)^{\sigma_l+1} \frac{\gamma_n}{1-\gamma_n} \frac{1}{\overline{W}_t^i} \quad (\text{III.87})$$

Wages therefore evolve as

$$W_t = \left[\theta_h \left(W_{t-1} \pi_{t-1}^{\iota_h} \pi^{1-\iota_h} \right)^{\frac{1}{1-\gamma_n}} + (1 - \theta_h) \overline{W}_t^{\frac{1}{1-\gamma_n}} \right]^{1-\gamma_n} \quad (\text{III.88})$$

The Financial Sector

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{III.89})$$

$$\frac{1}{R_t^*} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right] \quad (\text{III.90})$$

Remember that

$$\lambda_t = \epsilon_t^U (C_t^i - h_t C_t - 1^i)^{-\sigma_c} - \beta h E_t [\epsilon_{t+1}^U (C_{t+1}^i - h C_t^i)^{-\sigma_c}]$$

The UIP condition is similarly given by the households FOCs

$$\frac{1}{R_t} = \frac{1}{R_t^*} E_t \left[\frac{S_{t+1}}{S_t} \right] \quad (\text{III.91})$$

Tobin's Q is given by $q_t^i = \frac{\varphi_t^i}{\lambda_t^i}$ in

$$q_t^i = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(R_t^k Z_t^i - a(Z_t^i) + q_{t+1}^i (1 - \delta) \right) \right) \quad (\text{III.92})$$

More generally, the FOCs are given as

$$Equ_t^i : \quad -\frac{\lambda_t V_t^E}{P_t} + \beta \left(E \left(\lambda_{t+1} \frac{V_t^E + Div_{t+1}^i}{P_{t+1}} \right) \right) = 0 \quad (\text{III.93})$$

$$B_{t,t+m}^i : \quad -\lambda_t \frac{V_{t,t+m}^B}{P_t} + E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,t+m-1}^B}{P_{t+1}} \right] = 0 \quad (\text{III.95})$$

A real zero coupon bond returns one unit of consumption at maturity. For $j = 1$ it is

$$-\lambda_t \frac{V_{t,1}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,0}^B}{P_{t+1}} \right] \quad (\text{III.96})$$

$$\Leftrightarrow V_{t,1}^B = E_t \left[-\beta V_{t+1,0} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{III.97})$$

For $j = 2$ it is

$$-\lambda_t \frac{V_{t,2}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,1}}{P_{t+1}} \right] \quad (\text{III.98})$$

$$\Leftrightarrow V_{t,2}^B = E_t \left[-\beta V_{t+1,1} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{III.99})$$

$V_{t+1,1}$ is the price of a real bond of original maturity $m = 2$ with one period left. Assuming no arbitrage, this price equals the price of a $m = 1$ bond issued next period. Bond prices can thus be defined recursively (using $SDF_t = \beta \frac{\lambda_{t+1}}{\lambda_t}$)

$$V_{t,t+m}^B = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} V_{t+1,t+m-1}^B \frac{P_t}{P_{t+1}} \right] \quad (\text{III.100})$$

$$= E_t (SDF_{t+1} \pi_{t+1} V_{t+1,t+m-1}^B) \quad (\text{III.101})$$

Assuming $V_{1,t} = 1$ in terms of one unit of consumption we apply recursion and get

$$V_{t,t+m}^B = E_t ((SDF_{t+1} \pi_{t+1})^j) \quad (\text{III.102})$$

Real yields are then given by

$$R_{t+1,t+m}^B = (V_{t,t+m}^B)^{-\frac{1}{j}} \quad (\text{III.103})$$

Regarding the assets we derive

$$1 = E_t \left[-\beta \frac{P_t}{P_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \frac{V_t^E + Div_{t+1}}{V_t^E} \right]$$

with real return

$$R_{t+1}^E = \frac{V_t^E + Div_t}{V_t^E} \frac{P_t}{P_{t+1}}$$

III.7.2. Figures and Tables

Figure III.1.. Contractionary Monetary Policy Shock in Discrete time

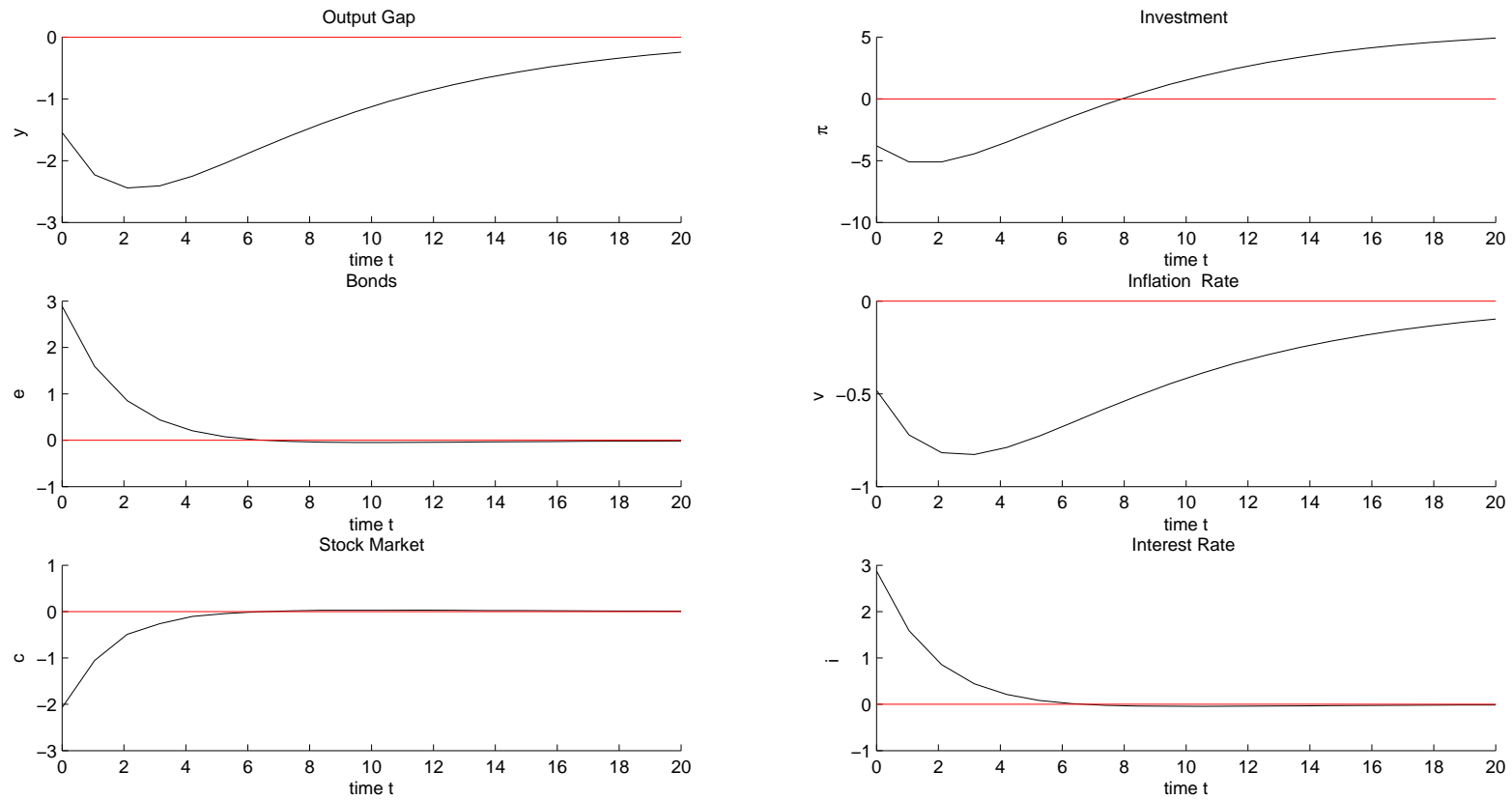


Figure III.2.. Contractionary Monetary Policy Shock in Continuous time

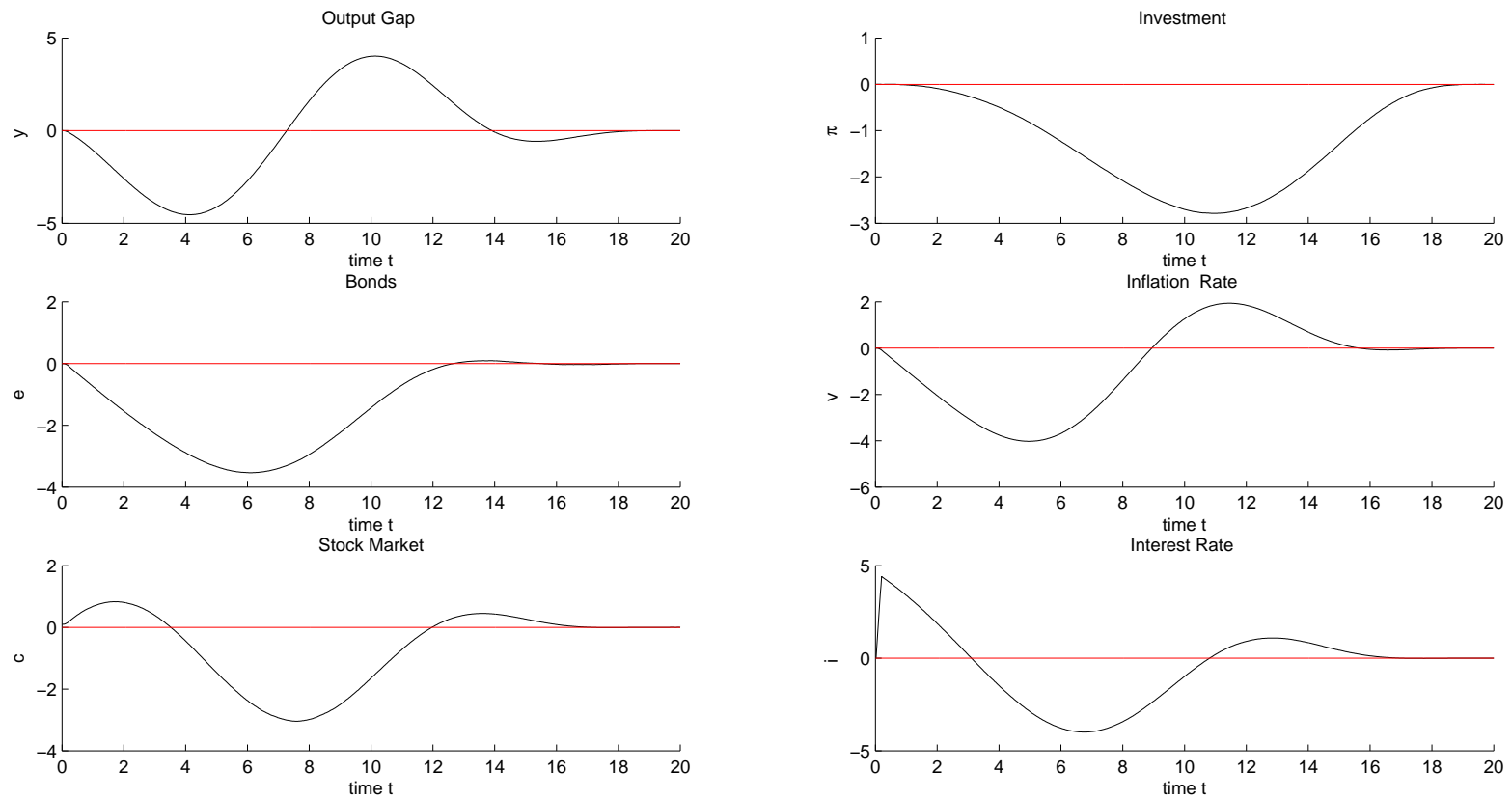


Figure III.3.. Negative Bond Market Shock in Discrete Time

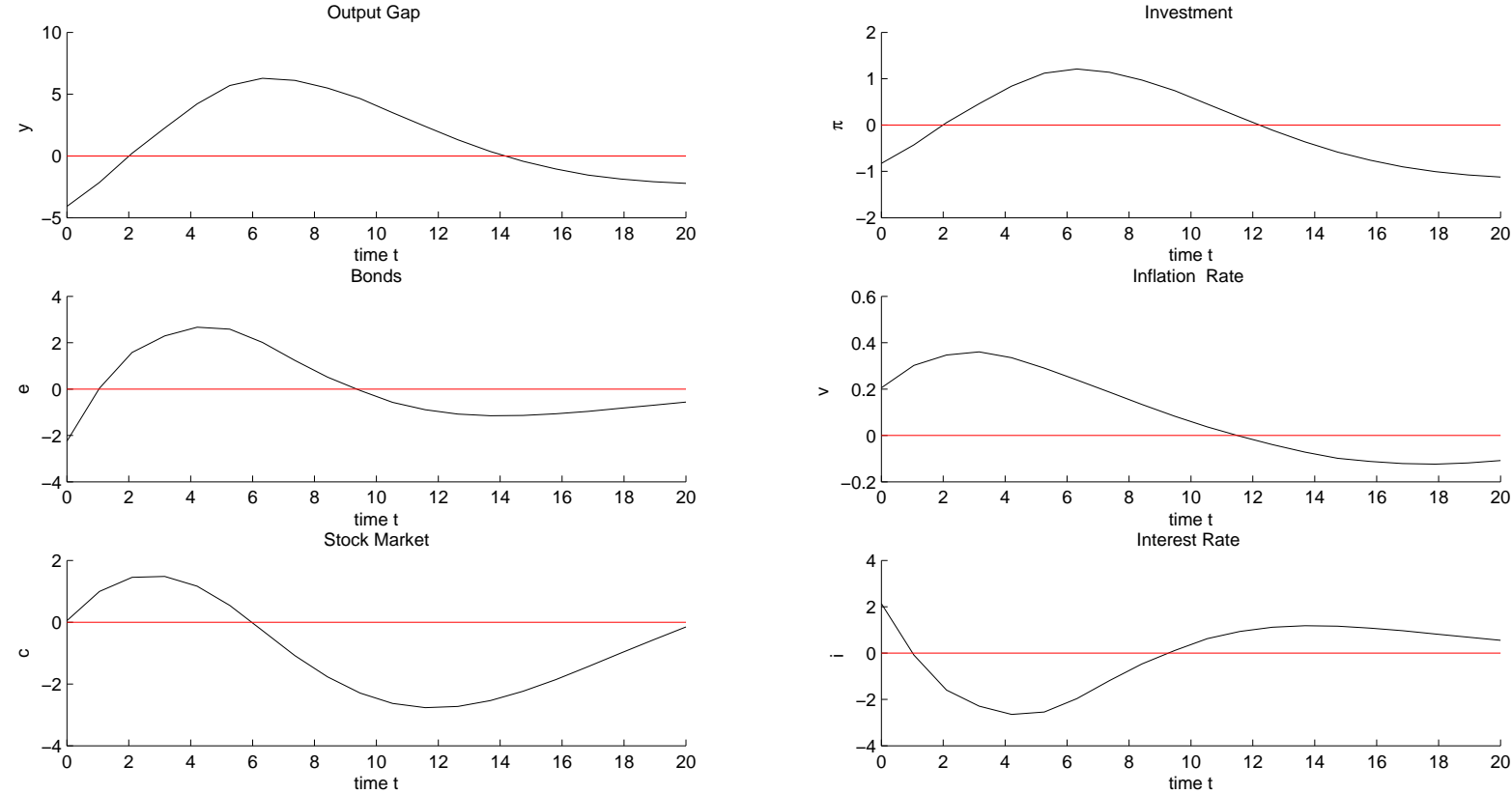
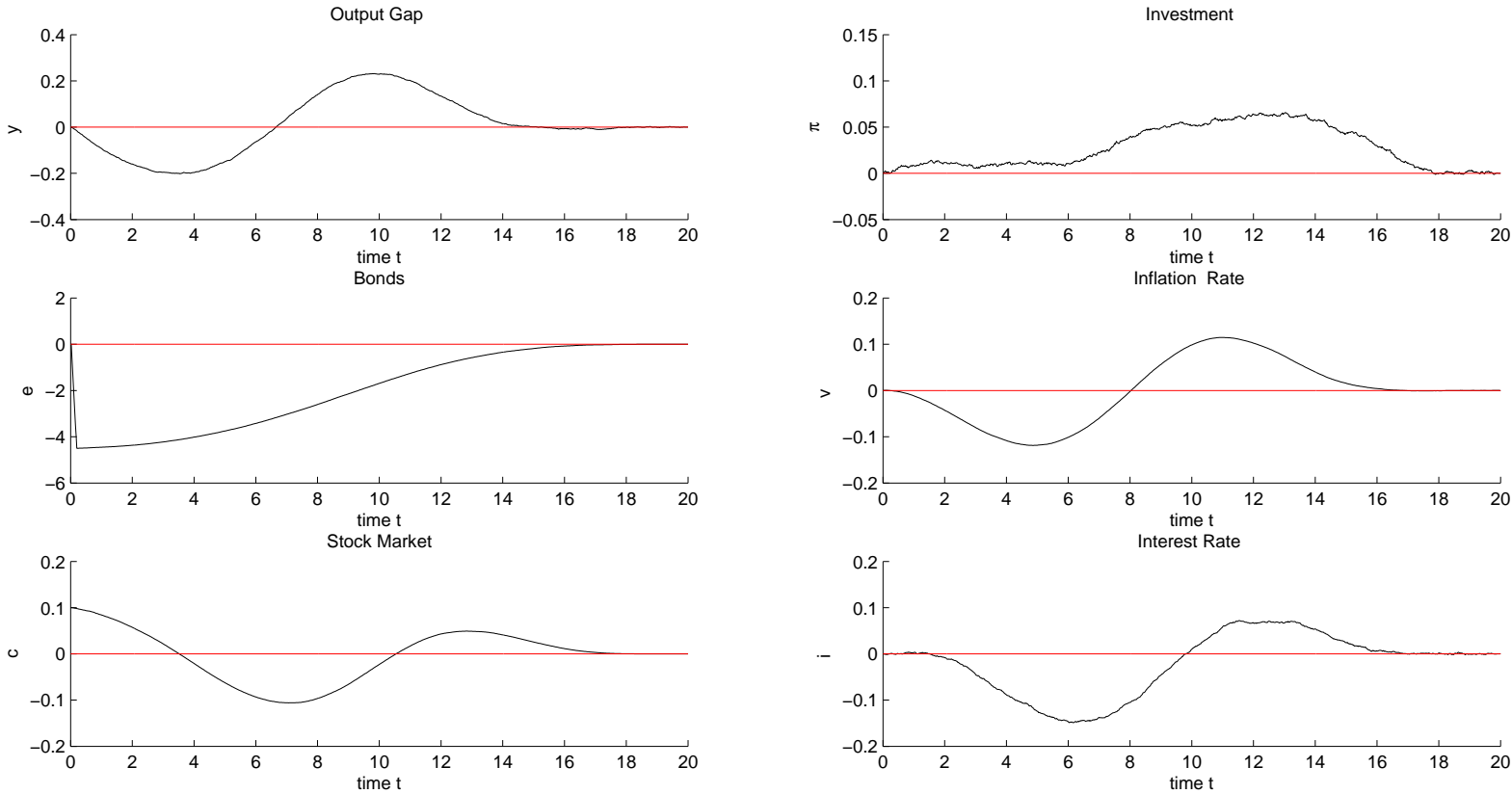


Figure III.4.. Negative Bond Market Shock in Continuous Time



(a) Continuous Time

Figure III.5.. Negative Stock Market Shock in Discrete Time

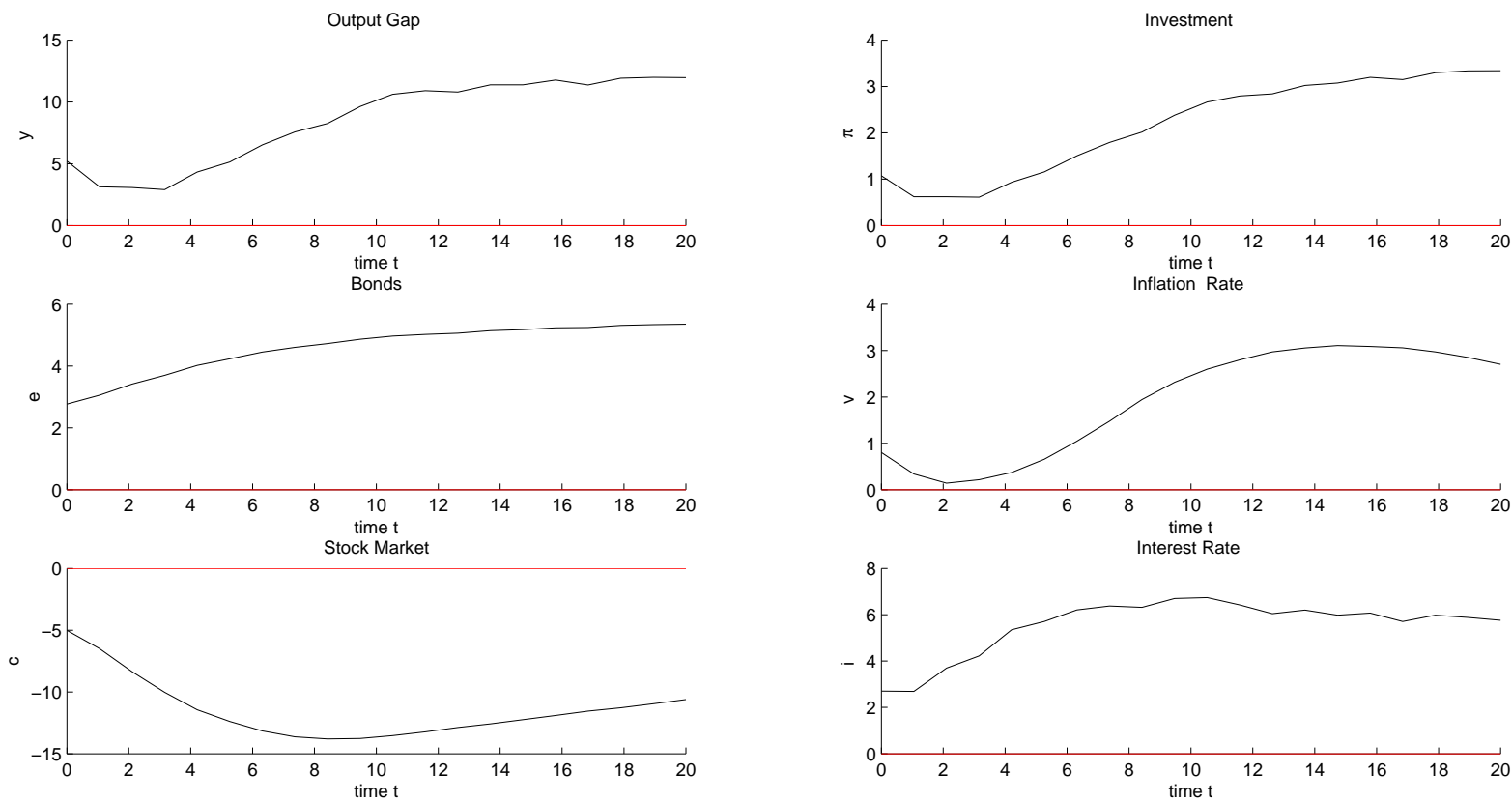
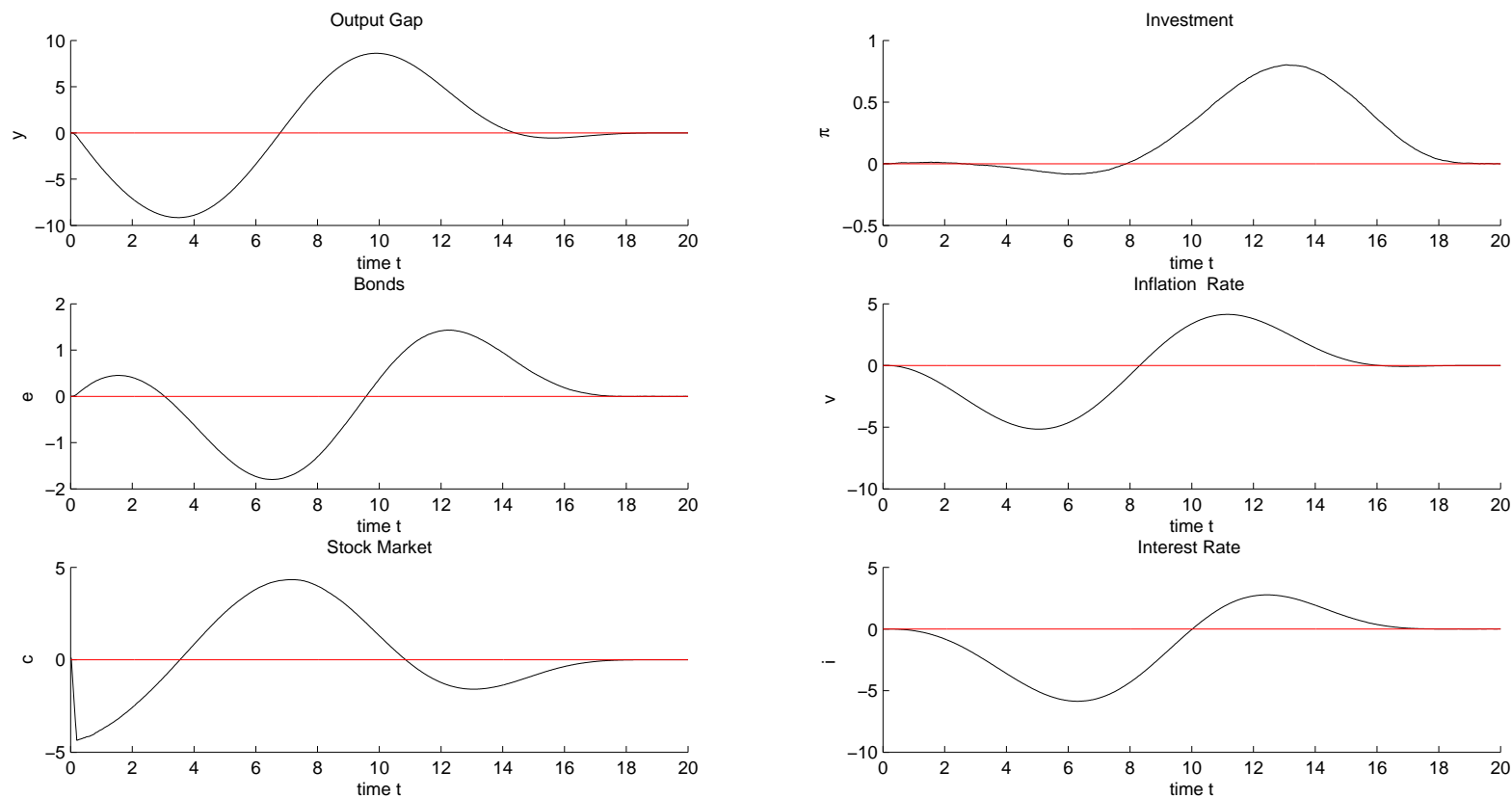
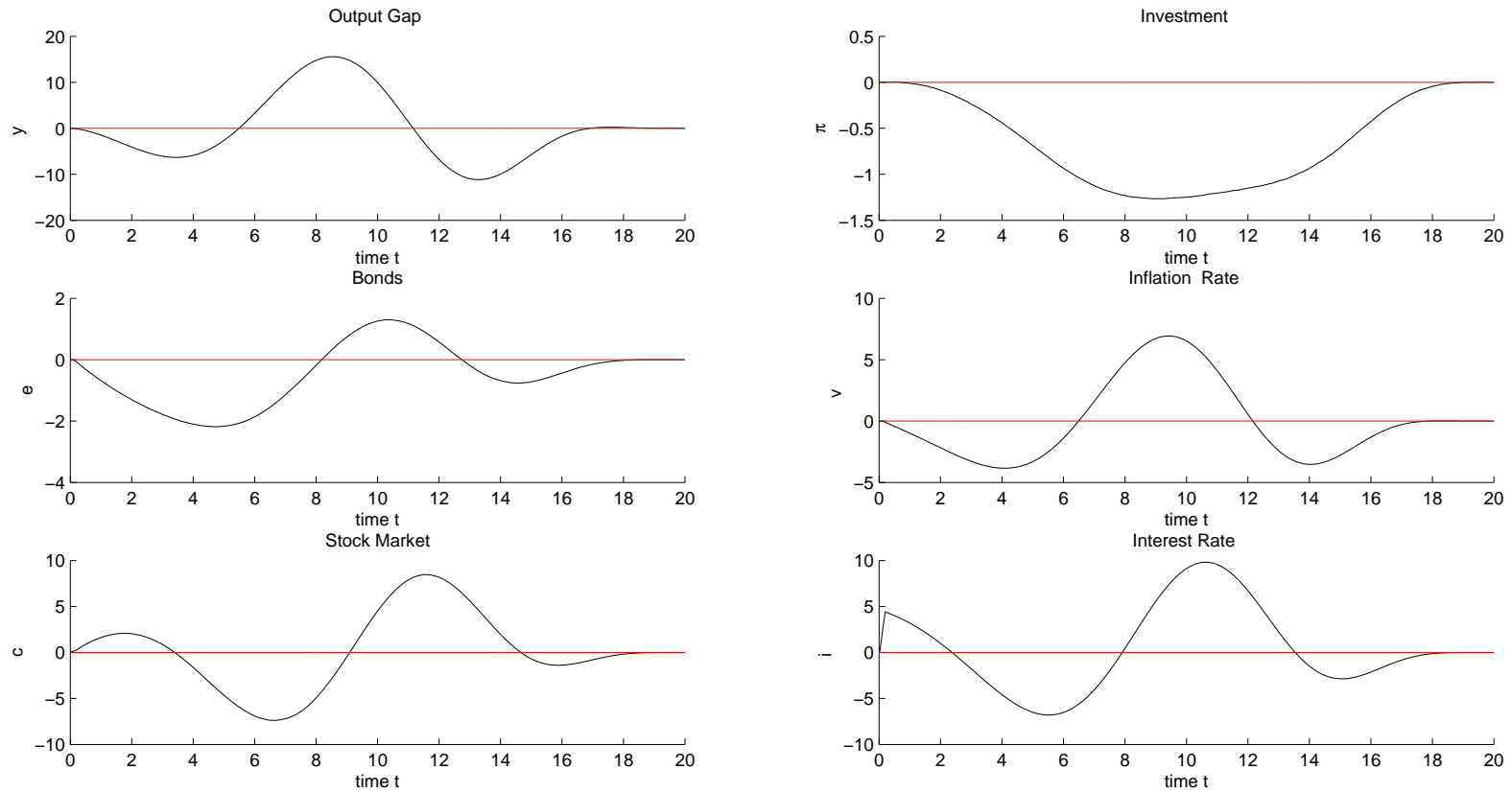


Figure III.6.. Negative Stock Market Shock in Continuous Time



(a) Continuous Time

Figure III.7.. Impulse Response Function: USA



(a) Contractionary Monetary Policy Shock

Table III.1.. Parameters, Priors and Posteriors

param	param value	distrib	prior		posterior	
			mean	variance	mean	variance
h	0.970	Beta	0.7	0.10	0.78	0.25
σ_c	1.000	N	1.5	0.40	0.98	0.98
σ_l	1.200	N	1.5	0.38	0.88	1.14
κ	9.510	N	4.0	1.50	10.1	4.23
α	0.210	N	0.3	0.05	0.35	0.19
θ	0.820	Beta	0.5	0.20	0.47	0.29
μ	0.630	Beta	0.5	0.20	0.61	0.29
θ_w	0.680	Beta	0.5	0.20	0.43	0.25
γ_n	0.620	Beta	0.5	0.20	0.62	0.27
ρ_R	0.770	Beta	0.5	0.20	0.90	0.26
ψ_y	0.190	Beta	0.5	0.20	0.57	0.27
ψ_π	1.290	N	0.0	2.0	5.01	6.35
ρ_b	0.200	N	0.0	2.0	1.77	2.74
ρ_y	0.200	N	0.0	2.0	0.13	0.12
ρ_π	0.200	N	0.0	2.0	2.14	1.56
γ_S	0.200	N	0.0	2.0	0.08	0.64
γ_i	0.200	N	0.0	2.0	0.46	1.41
γ_y	0.200	N	0.0	2.0	0.59	2.10
σ_b	0.500	-	-	-	-	-
σ	0.500	-	-	-	-	-
μ	0.400	-	-	-	-	-
κ	1.500	-	-	-	-	-
β	0.980	-	-	-	-	-
η_c	0.600	-	-	-	-	-
γ_1	0.050	-	-	-	-	-
γ_2	0.001	-	-	-	-	-
ι	0.710	-	-	-	-	-
ι_w	0.680	-	-	-	-	-
δ	0.025	-	-	-	-	-

Chapter IV.

Analysis of Monetary Policy Responses After Financial Market Crises in a Continuous Time New Keynesian Model

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Analysis of Monetary Policy Responses After Financial Market Crises in a Continuous Time New Keynesian Model

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Abstract

To analyse the interdependence between monetary policy and financial markets in the context of the recent financial crisis, we use stochastic differential equations to develop a dynamic, stochastic general equilibrium New Keynesian model of two open economies. Our focus is on how stock and housing market bubbles are transmitted to and affect the domestic real economy and the consequent contagious effects on foreign markets. We simulate adjustment paths for the economies under two monetary policy rules: a standard open-economy Taylor rule and a modified Taylor rule that takes into account stabilisation of financial markets as a monetary policy objective. The results suggest a clear trade-off for monetary policymakers: under the modified rule, a severe economic recession can be avoided after a financial crisis but only at the price of a strong hike in inflation during the crisis and much more volatile inflation patterns during normal times, compared to under the standard Taylor rule. Using Bayesian estimation techniques, we calibrate the model to the cases of the United States and Canada and find that the resulting economic adjustment paths are similar to the ones we obtained from the extended Taylor rule theoretical model.

KEYWORDS: New Keynesian Models, Financial Crisis, Dynamic Stochastic Full Equilibrium Continuous Time Model, Taylor Rule

JEL CLASSIFICATION: C02, C63, E44, E47, E52, F41

IV.1. Introduction

Many OECD countries are still recovering from the worst financial and economic crisis since the Great Depression. One important lesson learned from this experience is that stable financial markets are a precondition to macroeconomic stability. Indeed, the crisis was a forceful reminder that there are important linkages not only between different domestic financial markets but also between international financial markets, meaning that shocks originating in one financial market in one country can spillover to other financial markets in the same country as well as to financial markets in other countries. In North America and Europe, there has been unprecedented use of monetary policy to stabilise financial markets and the real economy. However, stabilisation policy itself generates spillovers to other countries, a fact often ignored.

Indeed, continuing to act as though there really is such a thing as purely national policy making in a globalised world could facilitate the spread of a crisis to other countries, with foreseeable and unfortunate results, if history is any guide. We believe a better understanding of the influence of financial market spillovers, as well as of foreign monetary policy, is crucial to appropriate national monetary policy. Thus, it is important to learn more about the consequences of policymaker reactions to financial turmoil and how these vary based on the degree of importance policymakers attach to domestic and foreign financial markets.

Although the recent financial crisis resulted in the development of macroeconomic models that have helped us understand what happened, given direction on how to clean up the mess, and provided suggestions for avoiding another crisis, most of these studies either use techniques from finance or macroeconomics (Aït-Sahalia, Cacho-Diaz and Laeven 2010; Bekaert, Hoerova and Lo Duca 2013; El-Khatib, Hajji and Al-Refai 2013; Gertler and Karadi 2011; Gertler, Kiyotaki and Queralto 2012). A detailed literature overview is provided by Brunnermeier and Sannikov (2012). In this paper, we build a bridge between macroeconomics and finance intended to achieve better understanding of the effects of financial markets on real markets. We study spillover effects between financial markets, as well as from financial markets to the real economy, both within one economy and across economies, and we analyse the economic consequences of different monetary policy responses. We develop a fully dynamic stochastic general equilibrium New Keynesian (NK) model of two open economies based on stochastic differential equations. In our simulation analysis, we compare a standard open-economy Taylor rule that focuses on stabilising output, inflation, and the exchange rate to a modified Taylor rule that additionally takes account of financial market stabilisation.

We argue that academic research can aid central banks by analysing the extent to which financial markets should be taken into consideration when formulating monetary policy. We thus explore the

consequences of treating seriously the interaction between financial markets, monetary policy, and the real economy in a globalised world by developing a fully dynamic theoretical modelling framework. We are particularly interested in the relationship between financial markets, financial crises, and monetary policy, which can be characterised by a substantial degree of simultaneity.

Given our open-economy setting, we need to include the foreign exchange market in addition to stock and bond markets. Clarida, Gali and Gertler (2002) incorporate the exchange rate in a NK two-country model in which domestic and foreign households have the same preferences. Under quite restrictive assumptions, they find that purchasing power parity (PPP) holds and that the consumption real exchange rate is constant. Gali and Monacelli (2005) expand on this approach by applying Calvo sticky pricing and analysing the policy effects of either a Taylor rule or an exchange rate peg. Engels (2009), in turn, extend this open-economy model by incorporating local currency pricing and allowing for differences in domestic and foreign household preferences. Including the exchange rate in the monetary policy analysis takes into account a large and important financial market and the exchange rate itself could also be viewed as a policy objective. For example, Leitimo and Soderstrom (2005) include exchange rate uncertainty in a NK model and analyse different monetary policy rules. They find evidence that an interest rate reaction function in the form of a Taylor rule incorporating the exchange rate works particularly well. Similarly, Wang and Wu (2012) report that in their analysis of a group of exchange rate models for 10 OECD countries, the Taylor rule performs best empirically as a monetary policy rule. Taylor (2001) discusses the role of the exchange rate in monetary policy rules. Based on these empirical and theoretical findings, we model the policy reaction function as a Taylor rule.

Our theoretical approach is somewhat similar to that of Asada, Chen, Chiarella and Flaschel (2006), Chen, Chiarella, Flaschel and Hung (2006) and Chen, Chiarella, Flaschel and Semmler (2006). These authors transform the Keynesian AS-AD model into a disequilibrium model with a wage-price spiral and include two Phillips curves, one targeting wages and the other targeting prices. The model is transformed into five differential equations-explaining real wages, real money balances, investment climate, labour intensity, and inflationary climate-and its dynamics are analysed extensively. Malikane and Semmler (2008b) extend this framework by including the exchange rate; Malikane and Semmler (2008a) consider asset prices. However, none of these studies includes two financial markets and the exchange rate, particularly not in a framework controlling for the simultaneity between monetary policy and financial markets. Thus, our paper makes several contributions to the literature. First, we follow Ball (1998) and derive the Taylor rule within the model by employing the nominal interest rate and the exchange rate as monetary policy targets. Moreover, we follow Bekaert, Cho and Moreno (2010) and Brunnermeier and Sannikov (2012) and model a financial market sector, which allows consistent inclusion of financial markets in

the policy rule. Faia and Monacelli (2007) provide empirical evidence that including financial market variables in the Taylor rule has a significant impact on actual decision-making processes. In a similar vein, Belke and Klose (2010) estimate Taylor rules for the European Central Bank (ECB) and the Federal Reserve (Fed) and include asset prices as additional monetary policy targets. We account for simultaneity between monetary policy and financial markets by incorporating several financial markets (i.e., foreign exchange, bond, and stock markets). The issue of simultaneity is empirically analysed by Bjornland and Leitemo (2009a), Rigobon (2003) and Rigobon and Sack (2003b). A theoretical discussion is provided by Hildebrand (2006).

Second, following Hayo and Niehof (2013a), we combine finance research with macroeconomic theory by employing a continuous-time framework. This allows us to use advanced techniques from the finance literature, such as jump-diffusion processes, to model financial markets. Technically, we transform the NK model into stochastic differential equations and compute solutions by means of advanced numerical algorithms. We use stochastic differential equations to tackle the issue of the nonlinear model. We thus avoid the need for third-order perturbation methods, as well as simplify model estimation. Yu (2013) states that continuous-time models should be very appealing to both economists and financial specialists because 'the economy does not cease to exist in between observations' (Bartlett 1946). On aggregate levels, economic decision-making almost always involves many agents and is typically conducted during the course of a month. As a result, continuous-time models may provide a good approximation of the actual dynamics of economic behaviour. Another important advantage of continuous-time models is that they provide a convenient mathematical framework for the development of financial economic theory, enabling simple and often analytically tractable ways to price financial assets. Continuous-time models can treat stock and flow variables separately and can be subjected to rigorous mathematical analysis (Thygesen 1997).

Third, to discover whether our theoretical analysis captures important aspects of real-world economies, we study the interaction between the United States and Canada. We estimate model parameters using Bayesian estimation techniques and compare the simulated adjustment paths to those from our model based on a priori calibration. The remainder of the paper is structured as follows. Section 2 derives the theoretical model. Section 3 briefly sketches the advantages of continuous-time modelling. In Section 4, we study the effects of financial market turmoil using dynamic simulations based on a calibrated version of the theoretical model and employing empirically estimated parameters. Section 5 concludes.

IV.2. Derivation of the Theoretical Model

IV.2.1. Placing the Model in the Literature

Our open-economy model begins with the typical New Keynesian (NK) approach of Blinder (1997), Clarida, Gali and Gertler (1999), Romer (2000b) and Woodford (1999) and, in line with Clarida, Gali and Gertler (2002), it incorporates the exchange rate. We also adopt the extensions of Gali and Monacelli (2005) and Engels (2009) that introduce Calvo pricing. Following Leitimo and Soderstrom (2005), we include exchange rate uncertainty in our NK model and analyse different monetary policy rules. Bekaert, Cho and Moreno (2010), Paoli, Scott and Weeken (2010b) and Wu (2006) discuss including a financial market sector in an extended NK model. Brunnermeier and Sannikov (2012) also attempts to include an advanced financial market, albeit not in a NK model. Other research concentrates on monetary policy transmission channels. For example, Curdia and Woodford (2008, 2010) and Woodford (2010), include the credit channel in their NK models, while Christiano, Motto and Rostagno (2010) and Gertler and Kiyotaki (2010) model a banking sector as a financial intermediary.

The switch from discrete to continuous time is in line with papers by Asada, Chen, Chiarella and Flaschel (2006), Chen, Chiarella, Flaschel and Hung (2006), Chen, Chiarella, Flaschel and Semmler (2006) and Malikane and Semmler (2008a,b), but no previous NK approach has taken this step. As argued in Hayo and Niehof (2013a), using a continuous-time framework makes it possible to consistently include state-of-the-art finance approaches in an open-economy NK macroeconomic framework, which is, to the best of our knowledge, a unique modelling approach. Thus, our core model is based on the New Keynesian model proposed by Smets and Wouters (2002, 2007). In addition, we follow Bekaert, Cho and Moreno (2010) and incorporate a financial sector, represented by various markets, so as to analyse domestic and international financial spillover effects. We work within a continuous-time framework, in line with Asada, Chen, Chiarella and Flaschel (2006), Chen, Chiarella, Flaschel and Hung (2006) and Chen, Chiarella, Flaschel and Semmler (2006). Hayo and Niehof (2013a) show that continuous-time models yield more realistic dynamic adjustment patterns compared to discrete-time models in otherwise similarly specified models. Here, we extend the closed-economy model in Hayo and Niehof (ibid.) to a two-country open-economy setting with different Taylor rules-a standard open-economy rule and a modified open-economy rule that takes financial market developments into account.

IV.2.2. Households

The representative household operates as a consumer with access to domestic and foreign goods. We assume that the economy is inhabited by a continuum of consumers $i \in [0, 1]$. First, we consider a

consumption index, such as that of Dixit and Stiglitz (1977), $C_t(P_t)$ which consists of domestic goods $c_t^{d,j}$, produced by firm j , and foreign goods $c_t^{f,j}$, produced by a foreign firm j . η_d^c and η_f^c are the domestic and foreign demand elasticities, respectively. Similarly, we define a production price index P_t , using $p_t^{d,j}$ and $p_t^{f,j}$.

Intermediate goods from abroad can be imported and turned into either final consumption goods or final investment goods. Both are modelled in accordance with Dixit and Stiglitz (ibid.)

$$C_t^{d,f} = \left(\int_0^1 ((C_t^j)^{d,f})^{\frac{1}{\mu_t^{cm}}} dj \right)^{\mu_t^{cm}} \quad (\text{IV.1})$$

We start by deriving the optimal consumption choice. The consumption index for all goods j is defined following Dixit and Stiglitz (ibid.)

$$C_t^d = \left[\int_0^1 (C_t^{d,j})^{\frac{\eta_d^c-1}{\eta_d^c}} dj \right]^{\frac{\eta_d^c}{\eta_d^c-1}} \quad (\text{IV.2})$$

$$C_t^f = \left[\int_0^1 (C_t^{f,j})^{\frac{\eta_f^c-1}{\eta_f^c}} dj \right]^{\frac{\eta_f^c}{\eta_f^c-1}} \quad (\text{IV.3})$$

where C_t^d is domestic consumption and C_t^f are imported consumption goods. η_d^c , η_f^c are the domestic elasticities of consumption for domestically and foreign produced goods, respectively.

Solving this equation by forming a Langrangian and deriving the first-order conditions (FOCs) reveals the typical characteristic of a Dixit-Stiglitz consumption index, namely

$$C_t = \left[\omega_f \frac{1}{\eta_c} (C_t^d)^{\frac{\eta_c-1}{\eta_c}} + (1 - \omega_f) \frac{1}{\eta_c} (C_t^f)^{\frac{\eta_c-1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c-1}} \quad (\text{IV.4})$$

where ω_f is the share of imports in consumption, and η_c is the elasticity of substitution between domestic and foreign goods.

In a similar manner, we define an investment index

$$I_t^d = \left(\int_0^1 ((I_t^j)^d)^{\frac{1}{\mu_t^i}} dj \right)^{\mu_t^i} \quad (\text{IV.5})$$

$$I_t^f = \left(\int_0^1 ((I_t^j)^f)^{\frac{1}{\mu_t^i}} dj \right)^{\mu_t^i} \quad (\text{IV.6})$$

and

$$I_t = \left[\omega_i^{\frac{1}{\eta_i}} (I_t^d)^{\frac{\eta_i-1}{\eta_i}} + (1 - \omega_i)^{\frac{1}{\eta_i}} (I_t^f)^{\frac{\eta_i-1}{\eta_i}} \right]^{\frac{\eta_i}{\eta_i-1}} \quad (\text{IV.7})$$

where $\omega_i f$ is the share of imports in investments. Foreign demand for domestic consumption and investment goods is given by

$$C_t^x = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_m} C_t^* \quad I_t^x = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_m} I_t^* \quad (\text{IV.8})$$

where C_t^*, I_t^*, P_t^* denote foreign aggregate consumption, investment and price level respectively. Accordingly, the aggregate price index is given by

$$P_t = \left[\omega (P_t^d)^{1-\eta_c} + (1 - \omega) (P_t^f)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}} \quad (\text{IV.9})$$

where ω is the share of imports. Associated prices are

$$P_t^d = \left[\int_0^1 (P_t^{d,j})^{1-\eta_d^c} dj \right]^{\frac{1}{1-\eta_d^c}} \quad (\text{IV.10})$$

$$P_t^f = S_t \left[\int_0^1 (P_t^{f,j})^{1-\eta_f^c} dj \right]^{\frac{1}{1-\eta_f^c}} \quad (\text{IV.11})$$

where S_t is the nominal exchange rate.

Consumption is maximised subject to $\int_0^1 (P_t^{d,j} C_t^{d,j} + P_t^{f,j} C_t^{f,j}) dj = Z_t$, where Z_t is expenditure. Optimisation yields

$$C_t^{d,j} = \left(\frac{P_t^{d,j}}{P_t^d} \right)^{-\eta_d^c} C_t^d \quad (\text{IV.12})$$

$$C_t^{f,j} = \left(\frac{P_t^{f,j}}{P_t^f} \right)^{-\eta_f^c} C_t^f \quad (\text{IV.13})$$

which can be transformed to

$$C_t^d = \omega_f \left(\frac{P_t^d}{P_t} \right)^{-\eta_c} C_t \quad (\text{IV.14})$$

$$C_t^f = (1 - \omega_f) \left(\frac{P_t^f}{P_t} \right)^{-\eta_c} C_t \quad (\text{IV.15})$$

Export firms face

$$X_t = \left(\int_0^1 \left((X_t^j)^m \right)^{\frac{1}{\mu_t^x}} dj \right)^{\mu_t^x} \quad (\text{IV.16})$$

where X is the export sector (as in Justiniano, Primiceri and Tambalotti (2010)), with time-varying mark-up μ_t^x .

Our discrete time model is based on Smets and Wouters (2002, 2007). We extend it following Paoli, Scott and Weeken (2010b) by including various types of assets in the household's budget constraint. We assume that there is a continuum of infinitely-lived households i .

Each household provides a different type of labour. Households seek to maximise the discounted sum of expected utilities with regard to consumption C_t , labour N_t and money M_t subject to a period-by-period budget constraint. Using a constant relative risk aversion utility function (CRRA), the representative household's lifetime utility can be written as

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^i \left(C_t^i, N_t^i, \frac{M_t^i}{P_t} \right) \quad (\text{IV.17})$$

where β is the discount factor. Specifically, it is

$$u_t^i = \epsilon_t^U \left(\frac{1}{1 - \sigma_c} (C_t^i - h C_{t-1}^i)^{1 - \sigma_c} + \frac{\epsilon_t^M}{1 - \sigma_m} \left(\frac{M_t^i}{P_t} \right)^{1 - \sigma_m} - \frac{\epsilon_t^L}{1 + \sigma_l} (N_t^i)^{1 + \sigma_l} \right) \quad (\text{IV.18})$$

where h represents an external habit formation, ϵ_t^U is a general shock to preferences, ϵ_t^L , and ϵ_t^M are specific shocks to labour and money and σ_c , σ_m and σ_l are elasticities of consumption, money and labour. Households maximise their utility due to the intertemporal budget constraint

$$\begin{aligned}
& \frac{W_t^i}{P_t} N_t^i + R_t^k Z_t^i K_{t-1}^i - a(Z_t^i) K_{t-1}^i - \frac{(M_t^i - M_{t-1}^i)}{P_t} \\
& - \frac{B_t^i R_t^{-1} - B_{t-1}^i}{P_t} - \frac{S_t (B_t^i)^* (R_t^*)^{-1} - S_t (B_{t-1}^i)^*}{P_t} \\
& - \sum_{j=0}^J \left(\frac{V_{t,t+m}^B}{P_t} B_{t,j}^i - \frac{V_{t-1,t+m-1}^B}{P_t} B_{t-1,t+m}^i \right) \\
& - \sum_{j=0}^J \left(S_t \frac{(V_{t,t+m}^B)^*}{P_t} (B_{t,t+m}^i)^* - S_t \frac{(V_{t,t+m-1}^B)^*}{P_t} (B_{t-1,t+m}^i)^* \right) \\
& - \frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t} + \frac{Div_t}{P_t} Equ_{t-1}^i \\
& - \frac{(S_t (V_t^E)^* (Equ_t^i)^* - S_t (V_{t-1}^E)^* (Equ_{t-1}^i)^*)}{P_t} \\
& + \frac{S_t Div_t^*}{P_t} (Equ_{t-1}^i)^* - C_t - I_t^i - A_t^i - T_t = 0
\end{aligned} \tag{IV.19}$$

where T are lump-sum taxes, W_t is the nominal wage rate, Div_t are dividends, and $(R_t^k Z_t^i - a(Z_t^i)) K_{t-1}^i$ is the return on the real capital stock minus capital utilisation costs. Furthermore, B_t^i and $B_t^{*,i}$ denote domestic and foreign one-period bonds, and $B_{t,j}^n$ denotes a m -period bond with $V_{t,t+m}^B$ as its price. S_t is the exchange rate, Equ_t^i is a share in an equity index with value V_t^E , and A_t^i are stage-contingent claims, and I_t^i are investments in capital.

Furthermore, the formation of the capital stock evolves as

$$K_t^i = (1 - \delta) K_{t-1}^i + \left(1 - V \left(\frac{I_t^i}{I_{t-1}^i} \right) \right) I_t^i \tag{IV.20}$$

where δ is the depreciation rate and investment adjustment cost function $V(\cdot)$ as in Smets and Wouters (2007).

IV.2.3. Domestic Firms

Domestic Firms

Final goods are derived under monopolistic competition using a CES function

$$Y_t = \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \tag{IV.21}$$

where Y_t^j is the input of the intermediate good and μ_t^d is a price elasticity. Final goods producers minimise their costs subject to the production function

$$\max \left(P_t Y_t - \int_0^1 P_t^j Y_t^j \right) \quad (\text{IV.22})$$

IV.2.4. Intermediate Firms

The intermediate goods Y_t^j are produced using a Cobb-Douglas production function

$$Y_t^j = z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{1-\alpha} \quad (\text{IV.23})$$

where Φ_t is the total factor productivity, ϵ_t^F is a technology shock, \tilde{K}_t are capital services (ZK_{t-1}), z_t is a technology shock to both domestic and foreign economies, and N_t is labour input. Firm profits are immediately paid out as dividends

$$\frac{Equ_{t-1}^j Div_t^j}{P_t} = \frac{P_t^j Y_t^j}{P_t} - \frac{W_t}{P_t} N_t^j - R_t^k \tilde{K}_t^j \quad (\text{IV.24})$$

Nominal profits for firm j are therefore given by

$$\frac{Equ_t^i Div_t^i}{P_t} \pi_t^j = \left(\frac{P_t^j}{P_t} - MC_t \right) Y_t^j = \left(\frac{P_t^j}{P_t} - MC_t \right) \left(\frac{P_t}{P_t^j} \right)^{\frac{-\mu_t^d}{\mu_t^d - 1}} Y_t \quad (\text{IV.25})$$

The pricing kernel is derived from the FOCs of the households

$$\frac{\lambda_t}{P_t} = \beta E_t \left(\frac{(1 + R_t) \lambda_{t+1}}{P_{t+1}} \right) \quad (\text{IV.26})$$

This gives the pricing kernel for the discount rate $\frac{1}{1+R_t}$.

Each period, a fraction of the firms $(1 - \theta)$ are able to adjust prices, while the remainder follow a rule of thumb. We denote $\pi_t = \frac{P_t}{P_{t-1}}$ and π is the steady state inflation. The optimisation problem of the price-adjusting firm is:

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\frac{\overline{P}_t^j}{P_{t+s}} \prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) - MC_{t+s} \right) Y_{t+s}^j \quad (IV.27)$$

$$s.t. \left(\frac{\overline{P}_t^j \prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l})}{P_{t+s}} \right)^{-\frac{\mu_{t+s}^d}{\mu_{t+s}^d - 1}} Y_{t+s} = Y_{t+s}^j \quad (IV.28)$$

For the sake of simplification, we define $-\frac{\mu_{t+s}^d}{\mu_{t+s}^d - 1} = \delta$ We obtain

$$P_t = \left[\theta \left(P_{t-1} \pi_{t-1}^l \pi^{1-l} \right)^{\frac{1}{1-\mu_t^d}} + (1-\theta) \overline{P}_t^{\frac{1}{1-\mu_t^d}} \right]^{1-\mu_t^d} \quad (IV.29)$$

IV.2.5. Wage Setting

Each household sells its labour based on the Stiglitz labour bundling function

$$N_t = \left(\int_0^1 (N_t^i)^{\frac{1}{\gamma_n}} \right)^{\gamma_n} \quad (IV.30)$$

where γ_n is the wage elasticity and $1 \leq \gamma_n < \infty$. Demand for labour is given by

$$N_t^i = \left(\frac{W_t^i}{W_t} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_t \quad (IV.31)$$

Households experience a changing wage with random probability $1-\theta_h$. The i^{th} household's reoptimised wage is \overline{W}_t^i , whereas the unchanged wage is given by $W_{t+1}^i = W_t^i \pi_t^{\iota_h} \pi^{1-\iota_h} \mu_z$, where μ_z is the steady state technological growth rate $\frac{z_{t+1}}{z_t}$. Households then maximise their optimal wage subject to the demand for labour and the budget constraint. Hence, wages evolve as

$$W_t = \left[\theta_h \left(W_{t-1} \pi_{t-1}^{\iota_h} \pi^{1-\iota_h} \mu_z \right)^{\frac{1}{1-\gamma_n}} + (1-\theta_h) \overline{W}_t^{\frac{1}{1-\gamma_n}} \right]^{1-\gamma_n} \quad (IV.32)$$

IV.2.6. The Financial Sector

We follow Bekaert, Cho and Moreno (2010) and Paoli, Scott and Weeken (2010b) and model bond and asset yields first in discrete time and then in to continuous time. Gertler, Kiyotaki and Queralto (2012) apply a micro-based model and incorporate a banking sector and financial frictions. However, we focus on spillovers from the asset markets to the real economy and we are less interested in analysing intermediaries. Brunnermeier and Sannikov (2012) construct a macroeconomic model with an emphasis on variations in risk preferences and extent of information across households and financial experts. How-

ever, since the authors do not model real economic effects, their framework is not appropriate for our focus on financial and macroeconomic spillovers under different monetary policy rules. Therefore, we extend the NK framework by Paoli, Scott and Weeken (2010b) by defining different term structures and rigidities and moving the analysis to an open-economy setting.

When there are no frictions, the model exhibits the classic equity and term premia puzzle. As demonstrated by Campbell and Cochrane (1999) in the context of endowment economies, the puzzle can be solved via use of consumption habits. By switching off capital adjustment costs, we confirm the results of Boldrin, Christiano and Fisher (2001) that, in a production economy, consumption habits by themselves are not sufficient. In other words, we need to ensure that households do not merely dislike consumption volatility, they have to be prevented from doing something about it; capital adjustment costs are one modelling device that can achieve this. The presence of state contingent claims implies that we can price all financial assets in the economy based on no-arbitrage arguments.

The presence of state contingent claims implies that we can price all financial assets in the economy based on no-arbitrage arguments.

We follow Binsbergen, Fernandez-Villaverde, Koijen and Rubio-Ramírez (2012) and Paoli, Scott and Weeken (2010b) and model the term structure recursively. The following equation describes the classic relationship based on one-period nominal bonds

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.33})$$

$$\frac{1}{R_t^*} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right] \quad (\text{IV.34})$$

The uncovered interest rate parity condition (UIP) condition is given by the households FOCs

$$\frac{1}{R_t} = \frac{1}{R_t^*} E_t \left[\frac{S_{t+1}}{S_t} \right] \quad (\text{IV.35})$$

Tobin's Q is $q_t^i = \frac{\varphi_t^i}{\lambda_t^i}$ in

$$q_t^i = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(R_t^k Z_t^i - a(Z_t^i) \right) + q_{t+1}^i (1 - \delta) \right) \quad (\text{IV.36})$$

A real zero-coupon bond returns one unit of consumption at maturity. For $j = 1$ it is

$$-\lambda_t \frac{V_{t,1}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,0}}{P_{t+1}} \right] \quad (\text{IV.37})$$

$$\Leftrightarrow V_{t,1}^B = E_t \left[-\beta V_{t+1,0} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.38})$$

$V_{t+1,1}$ is the price of a real bond of original maturity $m = 2$ with one period left. Assuming no arbitrage, this price equals the price of a $m = 1$ bond issued next period. Bond prices can thus be defined recursively (using $SDF_t = \beta \frac{\lambda_{t+1}}{\lambda_t}$)

$$V_{t,t+m}^B = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} V_{t+1,t+m-1}^B \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.39})$$

$$= E_t (SDF_{t+1} \pi_{t+1} V_{t+1,t+m-1}^B) \quad (\text{IV.40})$$

Assuming the price of a one-period bond to equal one ($V_{1,t} = 1$) in terms of one unit of consumption, we apply recursion and obtain

$$V_{t,t+m}^B = E_t ((SDF_{t+1} \pi_{t+1})^j) \quad (\text{IV.41})$$

Real yields are then given by

$$R_{t+1,t+m}^B = (V_{t,t+m}^B)^{-\frac{1}{j}} \quad (\text{IV.42})$$

The price of a one-period bond can also be written as

$$(V_{t,t+m}^B)^* = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} (V_{t+1,t+m-1}^B)^* \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.43})$$

$$(R_{t+1,t+m}^B)^* = ((V_{t,t+m}^B)^*)^{-\frac{1}{j}} \quad (\text{IV.44})$$

Regarding the assets, we derive

$$1 = E_t \left[-\beta \frac{P_t}{P_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \frac{V_t^E + Div_{t+1}}{V_t^E} \right]$$

with real return

$$R_{t+1}^E = \frac{V_t^E + Div_t}{V_t^E} \frac{P_t}{P_{t+1}}$$

is based on nonlinear but cointegrated relations. Thus, the model reconciles the non-stationary behaviour of consumption from the macroeconomics literature with the assumption of stationary interest rates in the finance literature¹. Therefore, approximation would lead to a great loss of information.

IV.2.7. The Monetary Policy Reaction Function

Since we want to compare two different types of monetary policy reaction, our simulations are based on two different Taylor rules. First, in line with Ball (1998), Justiniano, Primiceri and Tambalotti (2010), Leitemo and Soderstrom (2005), Lubik and Schorfheide (2007), Lubik and Smets (2005), Smets and Wouters (2007), Svensson (2000b) and Taylor (1993), we employ a standard open-economy Taylor rule. Second, we modify this standard Taylor rule by accounting for central bank reaction to financial market developments. The modified Taylor rule takes the following form

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\pi_t \pi}{\pi_{t-1}} \right)^{\psi_{\pi^i}} \left(\frac{\pi_t^f \pi^f}{\pi_{t-1}^f} \right)^{\psi_{\pi^f}} \left(\frac{Y_t}{Y_{t-1}} \right)^{\psi_Y} \left(\frac{S_t}{S_{t-1}} \right)^{\psi_S} \left(\frac{R_t^E}{R_{t-1}^E} \right)^{\psi_E} \right]^{1-\rho_{E^*}} \eta_{mp,t} \quad (\text{IV.45})$$

where R^E represents the entire financial market, including bonds and stocks and $\eta_{mp,t}$ is a monetary policy shock.

$$\log(\eta_{mp,t}) = \rho_{mp,t} \log(\eta_{mp,t-1}) + \epsilon_{mp,t} \quad (\text{IV.46})$$

where $\epsilon_{mp,t}$ is *i.i.d.* $N(0, \sigma_{mp}^2)$

Thus, our modified Taylor rule accounts for domestic and foreign output, the exchange rate, inflation and the financial market. The rule facilitates analysing the spillover effects between financial markets and monetary policy as well as between foreign and domestic policy. Moreover, by including the financial sector which consists of various markets, we account for a direct relationship between monetary policy and financial markets (Rigobon 2003; Rigobon and Sack 2003b).

In contrast to our detailed modelling of monetary policy, government spending is solely dependent on cash balances and lump-sum taxes.

IV.2.8. Market Clearing

To specifically analyse financial markets, we treat equities and bonds as financial instruments and assign them to a new sector, the financial market. A shortcoming of this sector is that it has no real purpose other than an allocative one. However, since our aim is to build a bridge between finance and

¹ Andreasen (2012), Andreasen (2010) and Wu (2006) show that this equals standard finance models such as Dai and Singleton (2000), Duffie and Kan (1996) and Duffie, Pan and Singleton (2000)

macroeconomic research, we model financial instruments stochastically and hence this solely allocative purpose is appropriate for our purposes. Thus, market clearing is given by

$$Y_t = C_t^d + C_t^f + I_t^d + I_t^f + FM^d + FM^f + a(Z_t)K_{t-1} + G_t \quad (\text{IV.47})$$

where FM is the financial market sector.

IV.3. The Continuous-Time Framework

To analyse discrete-time models, equities and bonds need to be linearised at least up to the second order; indeed, Andreasen (2012) even propose a third order so as to capture the time-varying effects of the term structure. However, linearisation would yield risk-neutral market participants, implying similar prices for all assets and making it difficult to study various financial markets Paoli, Scott and Weeken (2010b) and Wu (2006).

Hayo and Niehof (2013a) propose another way of solving the nonlinear DSGE model, namely, by switching to continuous time. Hence, we turn a system of difference equations into a system of continuous-time equations. This has the added advantage of being able to include financial instruments in a more sophisticated way without losing information due to approximation. Our specification of the financial sector reflects our assumption of a simultaneously interacting stock market and house price index. Following Heston (1993), we model the stock market as a stochastic volatility model. This approach is an extension of Black and Scholes (1973a) and takes account of the specific distribution of asset returns, leverage effects, and mean-reverting volatility, while remaining analytically tractable. To meet the assumption of highly interacting markets, we include the foreign stock market, house prices, exchange rates, output, and interest rates in the drift term of the stochastic differential equation. Shocks are included as Brownian motions. Including the output gap in the stock market follows Cooper and Priestley (2009) and Vivian and Wohar (2013); a general approach to incorporating macroeconomic factors in stock returns is developed by Pesaran and Timmermann (1995).

In line with Bayer, Ellickson and Ellickson (2010), house prices are modelled as stochastic differential equations taking into account local risk, national risk, and idiosyncratic risk. This allows modelling house prices in an asset-pricing environment. As before, we account for macroeconomic variables in the drift term. Consistent with empirical findings by Adams and Füss (2010), Agnello and Schuknecht (2011), Capozza, Hendershott, Mack and Mayer (2002) and Hirata, Kose, Otrok and Terrones (2012), we include the real interest rate, the output gap, and the derived asset from the stock market in the drift term to account for interconnectedness. To analyse call and put prices, we apply the extended Black-Scholes

formula as in Kou (2002). Turning to our continuous-time approach, the stochastic differential equations regarding the financial market can be expressed as:

$$dS = (S_t((r - \lambda\mu) + \rho_b b_t + \rho_b^* b_t^* + \rho_s^* S_t^* + \rho_i i_t + \rho_y y_t + \rho_e e_t + \rho_p i\pi_t))dt + \sqrt{V_t}dW_S(t) + \sum_{i=1}^{dN_t} J(Q_i) \quad (IV.48)$$

$$dV_t = \kappa(\theta - V_t)dt + \sigma\sqrt{V_t}dW_V(t)$$

$$dhb_t = (\gamma_h h_t + \gamma_S S_t + \gamma_s^* S_t^* + \gamma_h^* h_t^* + \gamma_y y_t - \gamma_i(i_t - \pi_t))dt + \sigma_1 dW_h^1(t) + \sigma_2 dW_h^2(t) + \sigma_3 dW_h^3(t) \quad (IV.49)$$

where $J(Q)$ is the Poisson jump-amplitude, Q is an underlying Poisson amplitude mark process ($Q = \ln(J(Q) + 1)$), and $N(t)$ is the standard Poisson jump-counting process with jump density λ and $E(dN(t)) = \lambda dt = Var(dN(t))$. dW_S and dW_V denote Brownian motions.

For example, we can then write the discrete model as

$$dK_t = (I_t - \delta K_t)dt + \left(1 + V\left(\frac{dI_t}{I_t dt}\right)\right) dI_t \quad (IV.50)$$

$$dY_t = dC_t + dI_t + dFM_t + dG_t + a(dZ_t)K_t dt \quad (IV.51)$$

Using some calculus, each difference equation can be transformed similarly into a differential equation (Hayo and Niehof 2013b).

IV.4. Studying the Reaction of Monetary Policy After a Financial Market Crash

IV.4.1. Simulating Economies

To analyse the contagious effects of financial crises for highly connected domestic and foreign real economies, we study the impulse responses following financial market turmoil in the form of a stock market and housing market crash. The second column of Table IV.1 contains the parameter values for our simulation analysis. Calibration of the household and firm side is standard. Elasticities of substitution regarding investments and consumption (η_d^c , η_d^i , η_f^c , η_f^i) vary between 1.30 and 1.50 (Fernández-Villaverde 2010). The household's utility function is similar to the one employed by Smets and Wouters (2007). The elasticity for substitution of consumption σ is 1.20; the elasticity of substitution for labour

σ_l is 1.25. On the supply side, we assume standard Calvo-pricing parameters as in Smets and Wouters (2007). The Calvo parameters for prices θ and wages θ_h are 0.75. We use monetary policy parameters similar to those of Adolfson, Laseen, Linde and Svensson (2011) and Lindé (2005). The monetary policy parameter reflects our assumption that monetary policy has multiple goals. Further details can be found in the cited literature. We compare the ensuing adjustment process based on the two types of Taylor rules outlined above: the standard Taylor rule and the modified Taylor rule that takes financial markets into account. By comparing the advantages and disadvantages of both policy rules, we will shed light on the question of whether central banks should directly respond to financial market developments.

We commence the analysis by simulating a stock market crisis. Technically, we take the mean of 100,000 simulations with 0.01 time steps, which we interpret as 20 quarters. We use a normalised Euler-Maruyama scheme to simulate the trajectories of the stochastic differential equations.

Figure IV.1 shows the impulse-response functions after a contractionary monetary policy shock under the modified Taylor Rule in the domestic economy. The adjustment found under the standard Taylor rule is similar to that found in the extant literature. In the figures, the black lines represent the domestic economy; the dashed lines show how the spillovers affect the foreign economy. Both economies are the same size and have the same parameters. As expected, the contractionary policy causes a decrease in the inflation rate. However, due to a worsening of investment conditions, output drops too, which then causes monetary policy to change path and decrease the interest rate again. Thus, we find that our model can replicate important aspects of a business cycle.

Figures IV.2 to IV.5 display the impulse responses after a stock market shock originating in the domestic economy. We differentiate between a minor upset and a major stock market crash. Reactions to both events have a similar pattern, but are notably different in terms of magnitude. In the case of the minor stock market upset (see Figure IV.2), output drops by less than 1 percentage point. Yet, the modified Taylor rule triggers an immediate interest rate drop, which leads to a booming real economy and a notable increase in the inflation rate. Thus, under the modified rule we observe a notable spillover from minor financial market movements to the real economy. In contrast, the original Taylor rule reacts negligibly and financial markets are left to recover more or less on their own. Thus, under a standard Taylor rule, small movements in financial markets have very little effect on the real economy.

In case of a severe crisis, under the standard Taylor rule, after the domestic stock market crash, output and consumption begin to decline. Moreover, financial markets are positively connected and thus the drop in the domestic stock market causes a decline in the domestic house price index. Thus, the stock market crisis turns into a general financial market crisis, which brings about a decline in output. Reacting to the recession, the central bank starts lowering the interest rate, which triggers a depreciation of the ex-

change rate and helps with the recovery of the domestic economy. The domestic stock market shock and the following recession spill over to the foreign economy, causing a negative stock market development and a real economic downturn. The appreciating foreign exchange rate hinders the recovery of foreign output and forces the foreign central bank to lower the interest rate by more than seems necessary given the relatively mild recession. This rather loose foreign monetary policy causes a notable increase in the foreign inflation rate. Thus, we find that in the standard Taylor rule case, there are symmetric spillovers in real and financial variables, but asymmetric spillovers in the case of the inflation rate.

Looking now at the modified Taylor rule case, Figure IV.4, reveals some noteworthy differences from the standard Taylor rule case. First, and perhaps not surprisingly, monetary policy reacts even more quickly and much more forcefully. As a consequence, the domestic recession is not as deep as in the case of the standard Taylor rule. Second, domestic financial markets recover more quickly. Third, given the extremely expansionary monetary policy, inflation starts rising. Again, we find the domestic situation spilling over to the foreign country. However, this time the adjustment is basically mirroring the domestic country's development.

Tables IV.2 and IV.3 compare adjustment following the crisis under the two different Taylor rules, which basically boils down to a trade-off. On the one hand, the output gap declines less when monetary policy directly reacts to financial market variables. On the other hand, the interest rate decreases twice as much under the modified rule, with the consequence of domestic inflation.

Next, we analyse a crash in the house price index, which, in our framework, represents a country's real estate market. Under a standard Taylor rule, a housing market crash causes a major economic downturn in the real economy, as housing is not just a financial instrument but also a sector of the real economy (see Figure IV.6). Under the standard Taylor rule, declining GDP leads monetary policymakers to lower the interest rate. After some time, real and financial variables recover toward the steady state. This development also occurs in the foreign economy, except that the appreciating exchange rate causes the foreign central bank to lower interest rates by more than is warranted by the rather mild recession, resulting in inflation. Under the modified Taylor rule (Figure IV.7), stabilisation of the output gap is achieved somewhat more quickly, but the attempt to stabilise financial markets leads to a strong decline in domestic interest rates, resulting in inflation. Thus, after some time, there is a surge in the inflation rate of both countries. In regard to domestic and international financial market spillovers, the domestic housing market crisis causes foreign house prices to decline, as well as domestic and foreign stock prices, thus illustrating the interconnectedness of financial markets, both within as well as across borders.

Tables IV.2 and IV.3 show the differences between the standard and modified Taylor rule. The smaller decline in the output gap and the greater increase in the inflation rate under the modified rule is clearly

demonstrated.

IV.4.2. Employing Empirically Estimated Parameters

To ensure that our theoretical simulations are compatible with empirical evidence, we estimate model parameters using data from Canada and the United States. Reflecting our use of continuous-time equations, we rely on stochastic estimation (approximate Bayesian computation; see Beaumont, Zhang and Balding (2002)).

Two inputs are crucial to obtaining plausible results via Markov Chain Monte Carlo (MCMC) estimations: the choice of priors and the choice of initial values. Our choice of prior distributions for NK models is similar to that of Smets and Wouters (2002, 2007), Negro, Schorfheide, Smets and Wouters (2007) or Lindé (2005).

We follow Kimmel (2007), Wright (2008) or Jones (2003) and choose normal distributions for our financial variables. The financial parameters take the natural conjugate g-prior specification so that each prior for a financial parameter is $N(0, \sigma^2 (X_i' X_i)^{-1})$, conditional on σ^2 . To account for quarterly data in macroeconomic variables, we select a tighter distribution and apply the standard normal distribution.

Data are obtained from the Bureau of Economic Analysis, the Federal Reserve Bank of St. Louis, the US Bureau of Labor Statistics, Statistics Canada, Datastream, and the OECD database. We employ quarterly data from 1981:Q1 to 2013:Q4. The output gap is based on the transitory component after applying the HP filter to logged quarterly GDP. The monetary policy interest rate is the short-term money market rate. The inflation series is constructed as $400(CPI_t/CPI_{t-1} - 1)$.

For the financial variables, we employ the major stock index in the United States, S&P, and that of Canada, TSX. We also include the housing market in both countries, represented by changes in the house price.

Columns 5 to 8 in Table IV.1 show that the posteriors are comparatively close to our calibrated parameters, suggesting that our choice of parameters for the simulation analyses is consistent with real-world data. Comparing the impulse-response functions given our estimated parameters, we observe a similar dynamic adjustment as described above (results available on request). This further supports our hypothesis of a strong linkage between monetary policy and financial markets and the importance of international spillovers.

We find spillover effects from monetary policy conducted by the United States, but only very small effects from policy initiated by the Bank of Canada. Moreover, US monetary policy appears to have a larger effect on Canada than does its own monetary policy. This finding is consistent with empirical evidence reported by Hayo and Neuenkirch (2012) on how monetary policy communication impacts

financial markets in the two countries. We find no evidence that the Taylor rules of either central bank incorporate financial market variables. In line with our theoretical analysis, this might have amplified the effects of the crisis but avoided increasing inflation.

IV.5. Conclusions

In this paper, we extend Smets and Wouters (2007) well-known open-economy New Keynesian model in two important ways. First, we include a well-developed financial sector and, second, we apply stochastic differential equations and conduct the analysis in a continuous-time framework. This allows us to employ classic research from the field of finance and model the financial sector by means of the housing and stock markets. Given our two-country framework, we model the financial sector both in the domestic and in the foreign economy, thereby taking into account international economic interdependence over and above any linkages through the exchange rate. Applying stochastic differential equations allows us to rely on established research in finance, for instance, that of Merton (1973). In particular, we specify the financial markets as jump-diffusion processes and use the Black-Scholes equations Black and Scholes (1973a) for call prices. Furthermore, we employ Lyapunov techniques Khasminskii (2012) to analyse the stability of the solutions and steady-state properties. We thus combine New Keynesian macroeconomic analysis, classic finance research, and standard mathematical procedures used for studying differential equations.

Our main research question concerns the effects of different monetary policy reactions and how variations in these affect the transmission of financial crises to real markets. Specifically, we compare a standard open-economy Taylor rule with a modified Taylor rule that directly takes financial market developments into account. In our simulation analysis based on theoretically derived impulse-response functions we find for both cases that a financial crisis, no matter whether it starts on the stock market or in the housing market, has negative spillovers to the domestic real economy. In addition, there are spillovers to the other country, both in terms of its financial markets as well as real economic variables. Given that we model the housing market as a sector of the real economy, the magnitude of the recession following a housing market crash is much larger than that which follows a stock market crash.

We also find notable differences in adjustment patterns depending on which type of Taylor rule is being applied. First, we discover that under a standard Taylor rule, the development of foreign variables mirrors that of domestic variables, but fluctuations are less pronounced. There is one exception, though, which is the inflation rate. The inflation rate remains roughly constant in the domestic economy, where the crisis originated, but it increases in the foreign country. This is because in the standard open-economy Taylor rule, the exchange rate is in the objective function of the central bank. Due to an appreciation of

the foreign currency against the domestic currency, the foreign central bank lowers the interest rate by more than would be strictly necessary to stabilise the drop in the output gap and the resulting extremely expansionary monetary policy causes inflation. In the modified Taylor rule that contains financial market variables, we find again that there will be inflation in the domestic economy, as now monetary policy rates are decreased not only to counter the recession but also to stabilise financial markets.

Second, we find that the modified Taylor rule leads to a faster adjustment of both the domestic and foreign economy after a financial market crisis, as monetary policy reacts more quickly and more decisively compared to what occurs under the standard Taylor rule. Thus, we find that choosing a monetary policy rule involves a trade-off. If, on the one hand, policymakers put more weight on a quick stabilisation of both financial markets and real variables, they should adopt the modified Taylor rule. If, on the other hand, policymakers are concerned about inflation, they may be well advised to operate under the standard Taylor rule. To see whether our theoretical models have any implications for the real world, we use data from the United States and Canada to estimate the model parameters. Applying approximate Bayesian estimation techniques, we find that the estimated parameters are quite similar to our theoretical priors. However, most likely due to difference in size of the two countries' economies, we find strong spillovers from the United States to the Canada, but only very weak spillovers in the other direction. We find no evidence that the Taylor rules of either central bank incorporate financial market variables, which could explain why there has not been higher inflation, even in the face of extensive use of monetary policy in the period after the crisis and continuing to the present.

Our study has some interesting policy implications. Taking financial markets directly into account in the Taylor rule mitigates the severity of economic recessions in the aftermath of financial crises. However, the price could be a higher inflation rate and more volatility of other variables. While this may be a small price to pay in the case of a severe crisis, during normal times, the typical up and down movements of financial markets will be transmitted to, and magnified in, other economic variables. Given the rarity of major crises in advanced economies, this suggests that perhaps monetary policy should not include financial variables in its reaction function, but should have an emergency plan for quickly replacing rule-based monetary policy with discretion-based policy in the event of a major financial crisis. Regarding the international dimensions, we find evidence that it is not only financial and real shocks that spill over to other countries, but also monetary policy actions. Thus, monetary policy in one country can substantially affect financial markets in other countries, even to the extent of triggering booms and busts. The impact and size of the effect depends on, first, the linkage between the markets and, second, the structure of the markets. Policymakers, particularly those of very open and well-integrated countries, should consider that spillovers from their countries could have international effects that (depending on

the degree of interaction) might be even larger than the intended effect on their own economy.

IV.6. Appendix

IV.6.1. Technical Appendix

Households

The household operates as a consumer with access to domestic and foreign goods. We assume that the economy is inhabited by a continuum of consumers $i \in [0, 1]$. First, we consider a consumption index, such as that of Dixit and Stiglitz (1977), $C_t(P_t)$, which consists of domestic goods $c_t^{d,j}$ produced by firm j and foreign goods $c_t^{f,j}$ produced by a foreign firm j . η_d^c and η_f^c are the demand elasticities. Similarly, we define a production index P_t , using $p_t^{d,j}$ and $p_t^{f,j}$.

Intermediate goods from abroad can be imported and turned into either final consumption goods or final investment goods. Both are modelled following Dixit and Stiglitz (ibid.)

$$C_t^m = \left(\int_0^1 ((C_t^j)^m)^{\frac{1}{\mu_t^{cm}}} dj \right)^{\mu_t^{cm}} \quad (\text{IV.52})$$

We start by finding the optimal consumption bundle. The consumption index for all goods j is defined, again following Dixit and Stiglitz (ibid.) as

$$C_t^d = \left[\int_0^1 (C_t^{d,j})^{\frac{\eta_d^c-1}{\eta_d^c}} dj \right]^{\frac{\eta_d^c}{\eta_d^c-1}} \quad (\text{IV.53})$$

$$C_t^f = \left[\int_0^1 (C_t^{f,j})^{\frac{\eta_f^c-1}{\eta_f^c}} dj \right]^{\frac{\eta_f^c}{\eta_f^c-1}} \quad (\text{IV.54})$$

where C_t^d is domestic consumption and C_t^f are imported consumption goods. η_d^c , and η_f^c are the elasticities of consumption for domestic and foreign goods, respectively.

Solving this equation by forming a Langrangian and deriving the first order conditions (FOC) reveals the typical characteristic of a Dixit-Stiglitz consumption index, namely

$$C_t = \left[\omega_f \frac{1}{\eta_c} (C_t^d)^{\frac{\eta_c-1}{\eta_c}} + (1 - \omega_f)^{\frac{1}{\eta_c}} (C_t^f)^{\frac{\eta_c-1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c-1}} \quad (\text{IV.55})$$

where ω_f is the share of imports in consumption, and η_c is the elasticity of substitution across the two categories of goods.

In a similar manner, we define an investment index

$$I_t^d = \left(\int_0^1 ((I_t^j)^d)^{\frac{1}{\mu_t^i}} dj \right)^{\mu_t^i} \quad (\text{IV.56})$$

$$I_t^f = \left(\int_0^1 ((I_t^j)^f)^{\frac{1}{\mu_t^i}} dj \right)^{\mu_t^i} \quad (\text{IV.57})$$

and

$$I_t = \left[\omega_i^{\frac{1}{\eta_i}} (I_t^d)^{\frac{\eta_i-1}{\eta_i}} + (1 - \omega_i)^{\frac{1}{\eta_i}} (I_t^f)^{\frac{\eta_i-1}{\eta_i}} \right]^{\frac{\eta_i}{\eta_i-1}} \quad (\text{IV.58})$$

where Foreign demand for domestic consumption and investment goods equals

$$C_t^x = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_m} C_t^* \quad I_t^x = \left(\frac{P_t^x}{P_t^*} \right)^{-\eta_{m_2}} I_t^* \quad (\text{IV.59})$$

where C_t^* , I_t^* , P_t^* denote foreign consumption, investment and price level, respectively. Accordingly, the aggregate price index is given by

$$P_t = \left[\omega (P_t^d)^{1-\eta_c} + (1 - \omega) (P_t^f)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}} \quad (\text{IV.60})$$

with associated prices

$$P_t^d = \left[\int_0^1 (P_t^{d,j})^{1-\eta_d^c} dj \right]^{\frac{1}{1-\eta_d^c}} \quad (\text{IV.61})$$

$$P_t^f = S_t \left[\int_0^1 (P_t^{f,j})^{1-\eta_f^c} dj \right]^{\frac{1}{1-\eta_f^c}} \quad (\text{IV.62})$$

where S_t is the nominal exchange rate.

Consumption is maximised subject to $\int_0^1 (P_t^{d,j} C_t^{d,j} + P_t^{f,j} C_t^{f,j}) dj = Z_t$, where Z_t are expenditures. Optimisation yields

$$C_t^{d,j} = \left(\frac{P_t^{d,j}}{P_t^d} \right)^{-\eta_d^c} C_t^d \quad (\text{IV.63})$$

$$C_t^{f,j} = \left(\frac{P_t^{f,j}}{P_t^f} \right)^{-\eta_f^c} C_t^f \quad (\text{IV.64})$$

This can be transformed into

$$C_t^d = \omega_f \left(\frac{P_t^d}{P_t} \right)^{-\eta_c} C_t \quad (\text{IV.65})$$

$$C_t^f = (1 - \omega_f) \left(\frac{P_t^f}{P_t} \right)^{-\eta_c} C_t \quad (\text{IV.66})$$

On the other hand, export firms face

$$X_t = \left(\int_0^1 \left((X_t^j)^m \right)^{\frac{1}{\mu_x}} dj \right)^{\mu_x} \quad (\text{IV.67})$$

The price setting problems of importing and exporting firms are completely analogous to those of domestic firms. Demand for the differentiated goods is modelled as in Adolfson, Laseen, Linde and Svensson (2011). Each household provides a different type of labour. Households seek to maximise the discounted sum of expected utilities with regard to consumption C_t , labour N_t and money M_t subject to a period-by-period budget constraint. Using a constant relative risk aversion utility function (CRRA), the representative household's lifetime utility can be written as

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^i \left(C_t^i, N_t^i, \frac{M_t^i}{P_t} \right) \quad (\text{IV.68})$$

where β is the discount factor. Specifically, it is

$$u_t^i = \epsilon_t^U \left(\frac{1}{1 - \sigma_c} (C_t^i - h C_{t-1}^i)^{1 - \sigma_c} + \frac{\epsilon_t^M}{1 - \sigma_m} \left(\frac{M_t^i}{P_t} \right)^{1 - \sigma_m} - \frac{\epsilon_t^L}{1 + \sigma_l} (N_t^i)^{1 + \sigma_l} \right) \quad (\text{IV.69})$$

where h represents external habit formation, ϵ_t^U is a general shock to preferences, ϵ_t^L , and ϵ_t^M are specific shocks to labour and money, and σ_c , σ_m , and σ_l are the elasticities of consumption, money and labour. Households maximise their utility based on the intertemporal budget constraint

$$\begin{aligned}
& \frac{W_t^i}{P_t} N_t^i + R_t^k Z_t^i K_{t-1}^i - a(Z_t^i) K_{t-1}^i - \frac{(M_t^i - M_{t-1}^i)}{P_t} \\
& - \frac{B_t^i R_t^{-1} - B_{t-1}^i}{P_t} - \frac{S_t (B_t^i)^* (R_t^*)^{-1} - S_t (B_{t-1}^i)^*}{P_t} \\
& - \sum_{j=0}^J \left(\frac{V_{t,t+m}^B}{P_t} B_{t,j}^i - \frac{V_{t-1,t+m-1}^B}{P_t} B_{t-1,t+m}^i \right) \\
& - \sum_{j=0}^J \left(S_t \frac{(V_{t,t+m}^B)^*}{P_t} (B_{t,t+m}^i)^* - S_t \frac{(V_{t,t+m-1}^B)^*}{P_t} (B_{t-1,t+m}^i)^* \right) \\
& - \frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t} + \frac{Div_t}{P_t} Equ_{t-1}^i \\
& - \frac{(S_t (V_t^E)^* (Equ_t^i)^* - S_t (V_{t-1}^E)^* (Equ_{t-1}^i)^*)}{P_t} \\
& + \frac{S_t Div_t^*}{P_t} (Equ_{t-1}^i)^* - C_t - I_t^i - A_t^i - T_t = 0
\end{aligned} \tag{IV.70}$$

Furthermore, households accumulate capital in the following form:

$$K_t^i = (1 - \delta) K_{t-1}^i + \left(1 - V \left(\frac{I_t^i}{I_{t-1}^i} \right) \right) I_t^i \tag{IV.71}$$

where δ is the depreciation rate and $V(\cdot)$ is as in Smets and Wouters (2002).

We obtain the first order conditions

$$C_t^i : \quad \epsilon_t^U (C_t^i - h_t C_{t-1}^i)^{-\sigma_c} - \beta h E_t [\epsilon_{t+1}^U (C_{t+1}^i - h C_t^i)^{-\sigma_c}] - \lambda_t = 0 \quad (\text{IV.72})$$

$$N_t^i : \quad \epsilon_t^U \epsilon_t^L (N_t^i)^{\sigma_L} - \lambda_t \frac{W_t^i}{P_t} = 0 \quad (\text{IV.73})$$

$$\frac{M_t^i}{P_t} : \quad \epsilon_t^U \epsilon_t^M \left(\frac{M_t^i}{P_t} \right)^{-\sigma_m} - \lambda_t + \beta E_t \left[\lambda_{t+1} \frac{P_t}{P_{t+1}} \right] = 0 \quad (\text{IV.74})$$

$$B_t^i : \quad -\frac{\lambda_t}{R_t P_t} + \beta E_t \left[\frac{\lambda_{t+1}}{P_{t+1}} \right] = 0 \quad (\text{IV.75})$$

$$B_t^{*,i} : \quad -\frac{S_t \lambda_t}{R_t^* P_t} + \beta E_t \left[\frac{S_{t+1} \lambda_{t+1}}{P_{t+1}} \right] = 0 \quad (\text{IV.76})$$

$$Z_t^i : \quad R_t^k - a'(Z_t^i) = 0 \quad (\text{IV.77})$$

$$K_t^i : \quad \beta E_t [\lambda_{t+1} (R_t^k Z_t^i - a(Z_t^i))] - \varphi_t + \beta E_t [\varphi_{t+1} (1 - \delta)] = 0 \quad (\text{IV.78})$$

$$I_t^i : \quad -\lambda_t + \varphi_t \left(1 - V \left(\frac{I_t^i}{I_{t-1}^i} \right) \right) - \varphi_t \left(\frac{I_t^i}{I_{t-1}^i} V' \left(\frac{I_t^i}{I_{t-1}^i} \right) \right) + \beta E_t \left(\varphi_{t+1} \left(\frac{I_{t+1}^i}{I_t^i} \right)^2 V' \left(\frac{I_{t+1}^i}{I_t^i} \right) \right) = 0 \quad (\text{IV.79})$$

$$Equ_t^i : \quad -\frac{\lambda_t V_t^E}{P_t} + \beta \left(E_t \left(\lambda_{t+1} \frac{V_{t+1}^E + Div_{t+1}^i}{P_{t+1}} \right) \right) = 0 \quad (\text{IV.80})$$

$$(Equ_t^i)^* : \quad -\frac{S_t \lambda_t (V_t^E)^*}{P_t} + \beta \left(E_t \left(\lambda_{t+1} \frac{S_{t+1} (V_{t+1}^E)^* + (S_{t+1} Div_{t+1}^i)^*}{P_{t+1}} \right) \right) = 0 \quad (\text{IV.81})$$

$$B_{t,t+m}^i : \quad -\lambda_t \frac{V_{t,t+m}^B}{P_t} + E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,t+m-1}^B}{P_{t+1}} \right] = 0 \quad (\text{IV.82})$$

$$(B_{t,t+m}^i)^* : \quad -\lambda_t \frac{(S_t V_{t,t+m}^B)^*}{P_t} + E_t \left[\beta \lambda_{t+1} \frac{(S_{t+1} V_{t+1,t+m-1}^B)^*}{P_{t+1}} \right] = 0 \quad (\text{IV.83})$$

Following Fernández-Villaverde (2010) we assume capital adjustment costs $a(\cdot)$ to be like

$$a(u) := \gamma_1(u - 1) + \gamma_2(u - 1)^2$$

The investment adjustment cost function is

$$S\left(\frac{x_t}{x_{t-1}}\right) = \frac{\kappa}{2} \left(\frac{x_t}{x_{t-1}} - \Lambda_x\right)^2$$

where $x_t = I_t^i$ and Λ_x is the growth rate of investment.

Firms

Domestic Firms

Final goods are derived under monopolistic competition using a CES function

$$Y_t = \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \quad (IV.84)$$

where Y_t^j is the input of the intermediate good and μ_t^d is a price mark-up. Final good producers minimise their costs subject to the production function

$$\max \left(P_t Y_t - \int_0^1 P_t^j Y_t^j \right) dj \quad (IV.85)$$

The first order conditions are given by

$$0 = -P_t^j + P_t \mu_t^d \left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d - 1} \left(\frac{1}{\mu_t^d} (Y_t^j)^{\frac{1 - \mu_t^d}{\mu_t^d}} \right) \quad (IV.86)$$

$$\Leftrightarrow 0 = -P_t^j + P_t \left(\left(\int_0^1 (Y_t^j)^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \right)^{\frac{\mu_t^d - 1}{\mu_t^d}} (Y_t^j)^{\frac{1 - \mu_t^d}{\mu_t^d}} \quad (IV.87)$$

$$\Leftrightarrow \frac{P_t^j}{P_t} = Y_t^{\frac{\mu_t^d - 1}{\mu_t^d}} (Y_t^j)^{-\frac{\mu_t^d - 1}{\mu_t^d}} \quad (IV.88)$$

$$\Leftrightarrow Y_t^j = \left(\frac{P_t}{P_t^j} \right)^{\frac{\mu_t^d}{\mu_t^d - 1}} Y_t \quad (IV.89)$$

Integrating Equation (IV.89) into Equation (IV.22) we obtain

$$Y_t = \left(\int_0^1 \left(\frac{P_t}{P_t^j} \right)^{\frac{\mu_t^d}{\mu_t^d-1}} Y_t^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \quad (\text{IV.90})$$

$$\Leftrightarrow Y_t = \left(\int_0^1 \left(\frac{P_t}{P_t^j} \right)^{\frac{1}{\mu_t^d-1}} Y_t^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \quad (\text{IV.91})$$

$$\Leftrightarrow Y_t = Y_t \left(\int_0^1 \left(\frac{P_t}{P_t^j} \right)^{\frac{1}{\mu_t^d}} dj \right)^{\mu_t^d} \quad (\text{IV.92})$$

$$\Leftrightarrow 1 = P_t^{\frac{\mu_t^d}{\mu_t^d-1}} \left(\int_0^1 (P_t^j)^{-\frac{1}{\mu_t^d-1}} dj \right)^{\mu_t^d} \quad (\text{IV.93})$$

$$\Leftrightarrow P_t^{-\frac{\mu_t^d}{\mu_t^d-1}} = \left(\int_0^1 (P_t^j)^{\frac{1}{1-\mu_t^d}} dj \right)^{\mu_t^d} \quad (\text{IV.94})$$

$$\Leftrightarrow P_t = \left(\int_0^1 (P_t^j)^{\frac{1}{1-\mu_t^d}} dj \right)^{1-\mu_t^d} \quad (\text{IV.95})$$

Intermediate Firms

The intermediate good Y_t^j is produced using a Cobb-Douglas production function

$$Y_t^j = z_t^{1-\alpha} \epsilon_t^F \Phi_t (\tilde{K}_t^j)^\alpha (N_t^j)^{1-\alpha} \quad (\text{IV.96})$$

where Φ_t is total factor productivity, ϵ_t^F is a technology shock, \tilde{K}_t are capital services, z_t is a technology shock to the domestic and foreign economies, and, N_t is labour input. Firm profits are immediately paid out as dividends

$$\frac{Equ_{t-1}^j Div_t^j}{P_t} = \frac{P_t^j}{P_t} Y_t^j - \frac{W_t}{P_t} N_t^j - R_t^k \tilde{K}_t^j \quad (\text{IV.97})$$

Firms minimise their costs with respect to the production technology

$$\tilde{K}_t^j : \quad R_t^k - \Gamma_t \alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha} \quad (\text{IV.98})$$

$$\Leftrightarrow \frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}} = \Gamma_t \quad (\text{IV.99})$$

$$N_t^j : \quad \frac{W_t}{P_t} - \Gamma(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha} = 0 \quad (\text{IV.100})$$

$$\Leftrightarrow \frac{W_t}{P_t(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha}} = \Gamma_t \quad (\text{IV.101})$$

with Γ_t marginal costs. This implies

$$\frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}} = \frac{W_t}{P_t(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha}} \quad (\text{IV.102})$$

$$\Leftrightarrow \frac{R_t^k}{W_t} = \frac{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^{\alpha-1} (N_t^j)^{1-\alpha}}{P_t(1-\alpha) z_t^{1-\alpha} \epsilon_t^F \Phi_t(\tilde{K}_t^j)^\alpha (N_t^j)^{-\alpha}} \quad (\text{IV.103})$$

$$\Leftrightarrow \frac{W_t}{R_t^k} = \frac{P_t(1-\alpha) \tilde{K}_t^j}{\alpha N_t^j} \quad (\text{IV.104})$$

$$\Leftrightarrow \tilde{K}_t^j = \frac{\alpha}{1-\alpha} \frac{W_t}{P_t R_t^k} N_t^j \quad (\text{IV.105})$$

We interpret the Lagrangian parameters as marginal costs

$$\frac{R_t^k}{\alpha z_t^{1-\alpha} \epsilon_t^F \Phi_t\left(\frac{\alpha}{1-\alpha} \frac{W_t}{P_t R_t^k} N_t^j\right)^{\alpha-1} (N_t^j)^{1-\alpha}} = MC_t \quad (\text{IV.106})$$

$$\Leftrightarrow \frac{(R_t^k)^\alpha \left(\frac{W_t}{P_t}\right)^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha} z_t^{1-\alpha} \epsilon_t^F \Phi_t} = MC_t \quad (\text{IV.107})$$

Nominal profits for firm j are therefore given by

$$\pi_t^j = \left(\frac{P_t^j}{P_t} - MC_t\right) Y_t^j = \left(\frac{P_t^j}{P_t} - MC_t\right) \left(\frac{P_t}{P_t^j}\right)^{\frac{-\mu_t^d}{\mu_t^d-1}} Y_t \quad (\text{IV.108})$$

The pricing kernel is derived from the FOCs of the households

$$\frac{\lambda_t}{P_t} = \beta E_t \left(\frac{(1+R_t) \lambda_{t+1}}{P_{t+1}} \right) \quad (\text{IV.109})$$

$$\Leftrightarrow \beta E_t(1+R_t) = E_t \frac{P_{t+1}}{\lambda_{t+1}} \frac{\lambda_t}{P_t} \quad (\text{IV.110})$$

This gives the pricing kernel for the discount rate $\frac{1}{1+R_t}$.

Each period a fraction of firms $(1 - \theta)$ is able to adjust prices, the remaining fraction follows a rule of thumb. We denote $\pi_t = \frac{P_t}{P_{t-1}}$ and π is the steady state inflation.

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\frac{\overline{P}_t^j}{P_{t+s}} \prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) - MC_{t+s} \right) Y_{t+s}^j \quad (\text{IV.111})$$

$$s.t. \left(\frac{\overline{P}_t^j \prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l})}{P_{t+s}} \right)^{-\frac{\mu_{t+s}^d}{\mu_{t+s}^d - 1}} Y_{t+s} = Y_{t+s}^j \quad (\text{IV.112})$$

We define $-\frac{\mu_{t+s}^d}{\mu_{t+s}^d - 1} = \mu_z$. The FOC is

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\left(\frac{1}{P_{t+s}} \overline{P}_t^j \prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) \right)^{\mu_z + 1} \frac{Y_{t+s}}{P_{t+s}^{\mu_z}} - MC_{t+s} \left(\overline{P}_t^j \prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) \right)^{\mu_z} \frac{Y_{t+s}}{P_{t+s}^{\mu_z}} \right) \quad (\text{IV.113})$$

Furthermore,

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\left(\frac{1}{P_{t+s}} \right)^{\mu_z} \overline{P}_t^{\mu_z} (\mu_z + 1) \left(\prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) \right)^{\mu_z + 1} \frac{Y_{t+s}}{P_{t+s}^{\mu_z}} \right. \\ \left. - E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(MC_{t+s} \mu_z \overline{P}_t^{\mu_z} \left(\prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) \right)^{\mu_z} \frac{Y_{t+s}}{P_{t+s}^{\mu_z}} \right) = 0 \quad (\text{IV.114}) \right.$$

$$E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\left(\overline{P}_t^j \right)^{\mu_z} \left(\prod_{l=1}^s \frac{1}{\pi_{t+l}} \right)^{1+\mu_z} (1 + \mu_z) \left(\prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) \right)^{\mu_z + 1} Y_{t+s} \right) \\ - E_t \sum_{s=0}^{\infty} (\beta\theta)^s \frac{\lambda_{t+s}}{\lambda_t} \left(\mu_z MC_{t+s} \left(\overline{P}_t^j \right)^{\mu_z - 1} \left(\prod_{l=1}^s \frac{1}{\pi_{t+l}} \right)^{\mu_z} \left(\prod_{l=1}^s (\pi_{t+l-1}^l \pi^{1-l}) \right)^{\mu_z} Y_{t+s} \right) = 0 \quad (\text{IV.115})$$

We obtain

$$P_t = \left[\theta \left(P_{t-1} \pi_{t-1}^l \pi^{1-l} \right)^{\frac{1}{1-\mu_t^d}} + (1 - \theta) \overline{P}_t^{\frac{1}{1-\mu_t^d}} \right]^{1-\mu_t^d} \\ \Leftrightarrow 1 = \left[\theta \left(\pi_{t-1} \pi_{t-1}^l \pi^{1-l} \right)^{\frac{1}{1-\mu_t^d}} + (1 - \theta) (\overline{P}_t^*)^{\frac{1}{1-\mu_t^d}} \right]^{1-\mu_t^d} \quad (\text{IV.116})$$

Wage Setting

Each household sells his labour based on the production function

$$N_t = \left(\int_0^1 (N_t^i)^{\frac{1}{\gamma_n}} \right)^{\gamma_n} \quad (\text{IV.117})$$

where γ_n is the wage mark-up and $1 \leq \gamma_n < \infty$. The demand for labour is given by

$$N_t^i = \left(\frac{W_t^i}{W_t} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_t \quad (\text{IV.118})$$

Households face a random probability $1 - \theta_h$ of changing nominal wage. The i^{th} household's reoptimised wage is \overline{W}_t^i , whereas the unchanged wage is given by $W_{t+1}^i = W_t^i \pi_t^{\iota_h} \pi^{1-\iota_h} \mu_z$, where μ_z is the technological growth rate $\frac{z_{t+1}}{z_t}$. Households then maximise their optimal wage subject to the demand for labour and the budget constraint.

$$N_{t+s}^i = \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z)}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \quad (\text{IV.119})$$

The Langrangian function is

$$\begin{aligned} E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s & \left(-\frac{\epsilon_{t+s}^L}{1 + \sigma_l} (N_{t+s}^i)^{1+\sigma_l} + \lambda_{t+s} \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z)}{P_{t+s}} N_{t+s} \right) \right) \\ + E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s & \left(\lambda_{t+s}^b \left(N_t^i - \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z)}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \right) \right) \end{aligned} \quad (\text{IV.120})$$

FOCs

$$\begin{aligned} \overline{W}_t^i : & \quad E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s \left(\lambda_{t+s} \frac{\prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z)}{P_{t+s}} N_{t+s} \right) \\ & - E_t \sum_{s=0}^{\infty} (\beta \theta_h)^s \left(\epsilon_{t+s}^L \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z)}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \right)^{\sigma_l+1} \frac{\gamma_n}{1-\gamma_n} \frac{1}{\overline{W}_t^i} \end{aligned} \quad (\text{IV.121})$$

Wages therefore evolve as

$$W_t = \left[\theta_h (W_{t-1} \pi_{t-1}^{\iota_h} \pi^{1-\iota_h} \mu_z)^{\frac{1}{1-\gamma_n}} + (1 - \theta_h) \overline{W}_t^{\frac{1}{1-\gamma_n}} \right]^{1-\gamma_n} \quad (\text{IV.122})$$

The Financial Sector

We follow Binsbergen, Fernandez-Villaverde, Koijen and Rubio-Ramírez (2012) and Paoli, Scott and Weeken (2010b) and model the term structure recursively. Using one-period nominal bonds, we derive the classic relationship

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.123})$$

$$\frac{1}{R_t^*} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right] \quad (\text{IV.124})$$

Remember that

$$\lambda_t = \epsilon_t^U (C_t^i - h_t C_t - 1^i)^{-\sigma_c} - \beta h E_t [\epsilon_{t+1}^U (C_{t+1}^i - h C_t^i)^{-\sigma_c}]$$

The UIP condition is similarly given by the households' FOCs

$$\frac{1}{R_t} = \frac{1}{R_t^*} E_t \left[\frac{S_{t+1}}{S_t} \right] \quad (\text{IV.125})$$

Tobin's Q is defined by $q_t^i = \frac{\varphi_t^i}{\lambda_t^i}$ in

$$q_t^i = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \left(R_t^k Z_t^i - a(Z_t^i) + q_{t+1}^i (1 - \delta) \right) \right) \quad (\text{IV.126})$$

More generally, the FOCs are given as

$$(\text{IV.127})$$

$$Equ_t^i : -\frac{\lambda_t V_t^E}{P_t} + \beta \left(E \left(\lambda_{t+1} \frac{V_{t+1}^E + Div_{t+1}^i}{P_{t+1}} \right) \right) = 0 \quad (\text{IV.128})$$

$$(Equ_t^i)^* : -\frac{S_t \lambda_t (V_t^E)^*}{P_t} + \beta \left(E \left(\lambda_{t+1} \frac{S_{t+1} (V_{t+1}^E)^* + (S_{t+1} Div_{t+1}^i)^*}{P_{t+1}} \right) \right) = 0 \quad (\text{IV.129})$$

$$B_{t,t+m}^i : -\lambda_t \frac{V_{t,t+m}^B}{P_t} + E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,t+m-1}^B}{P_{t+1}} \right] = 0 \quad (\text{IV.130})$$

$$(B_{t,t+m}^i)^* : -\lambda_t \frac{(S_t V_{t,t+m}^B)^*}{P_t} + E_t \left[\beta \lambda_{t+1} \frac{(S_{t+1} V_{t+1,t+m-1}^B)^*}{P_{t+1}} \right] = 0 \quad (\text{IV.131})$$

A real zero coupon bond returns one unit of consumption at maturity. For $m = 1$ this is

$$-\lambda_t \frac{V_{t,1}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,0}}{P_{t+1}} \right] \quad (\text{IV.132})$$

$$\Leftrightarrow V_{t,1}^B = E_t \left[-\beta V_{t+1,0} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.133})$$

For $m = 2$ it is

$$-\lambda_t \frac{V_{t,2}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,1}}{P_{t+1}} \right] \quad (\text{IV.134})$$

$$\Leftrightarrow V_{t,2}^B = E_t \left[-\beta V_{t+1,1} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.135})$$

$V_{t+1,1}^B$ is the price of a real bond of original maturity $m = 2$ with one period left. Assuming no arbitrage, this price equals the price of a $m = 1$ bond issued next period. Bond prices can thus be defined recursively (using $SDF_t = \beta \frac{\lambda_{t+1}}{\lambda_t}$)

$$V_{t,t+m}^B = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} V_{t+1,t+m-1}^B \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.136})$$

$$= E_t (SDF_{t+1} \pi_{t+1} V_{t+1,t+m-1}^B) \quad (\text{IV.137})$$

Assuming $V_{1,t} = 1$ in terms of one unit of consumption we apply recursion and obtain

$$V_{t,t+m}^B = E_t ((SDF_{t+1} \pi_{t+1})^j) \quad (\text{IV.138})$$

Real yields are then given by

$$R_{t+1,t+m}^B = (V_{t,t+m}^B)^{-\frac{1}{j}} \quad (\text{IV.139})$$

Similarly the following equation holds

$$(V_{t,t+m}^B)^* = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} (V_{t+1,t+m-1}^B)^* \frac{P_t}{P_{t+1}} \right] \quad (\text{IV.140})$$

$$(R_{t+1,t+m}^B)^* = ((V_{t,t+m}^B)^*)^{-\frac{1}{j}} \quad (\text{IV.141})$$

Regarding the financial variables we derive

$$1 = E_t \left[-\beta \frac{P_t}{P_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \frac{V_t^E + Div_{t+1}}{V_t^E} \right]$$

with real return

$$R_{t+1}^E = \frac{V_t^E + Div_t}{V_t^E} \frac{P_t}{P_{t+1}}$$

IV.6.2. Figures and Tables

Figure IV.1.. Monetary Policy Shock - Modified Monetary Policy

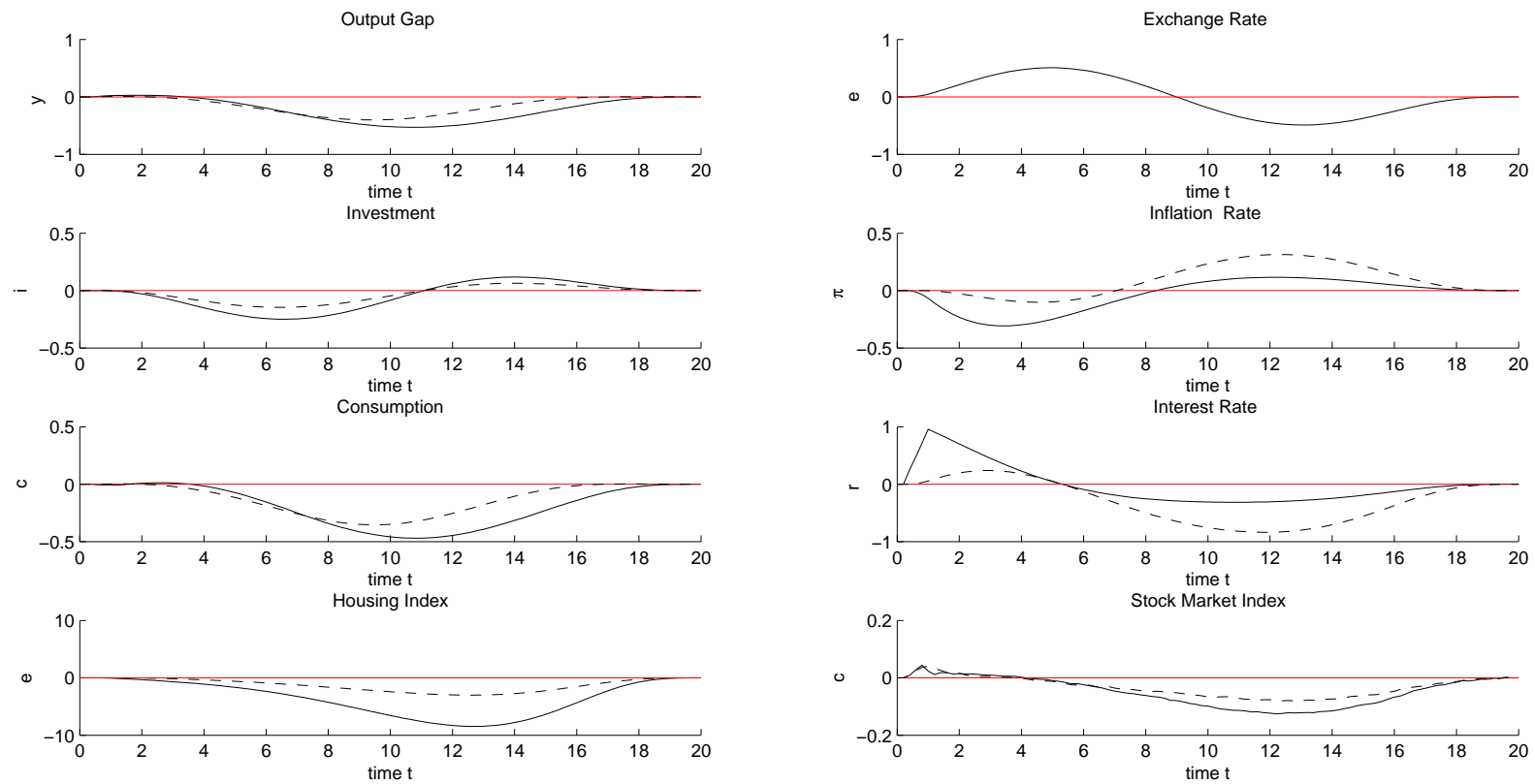


Figure IV.2.. Minor Stock Market Crisis - Modified Monetary Policy

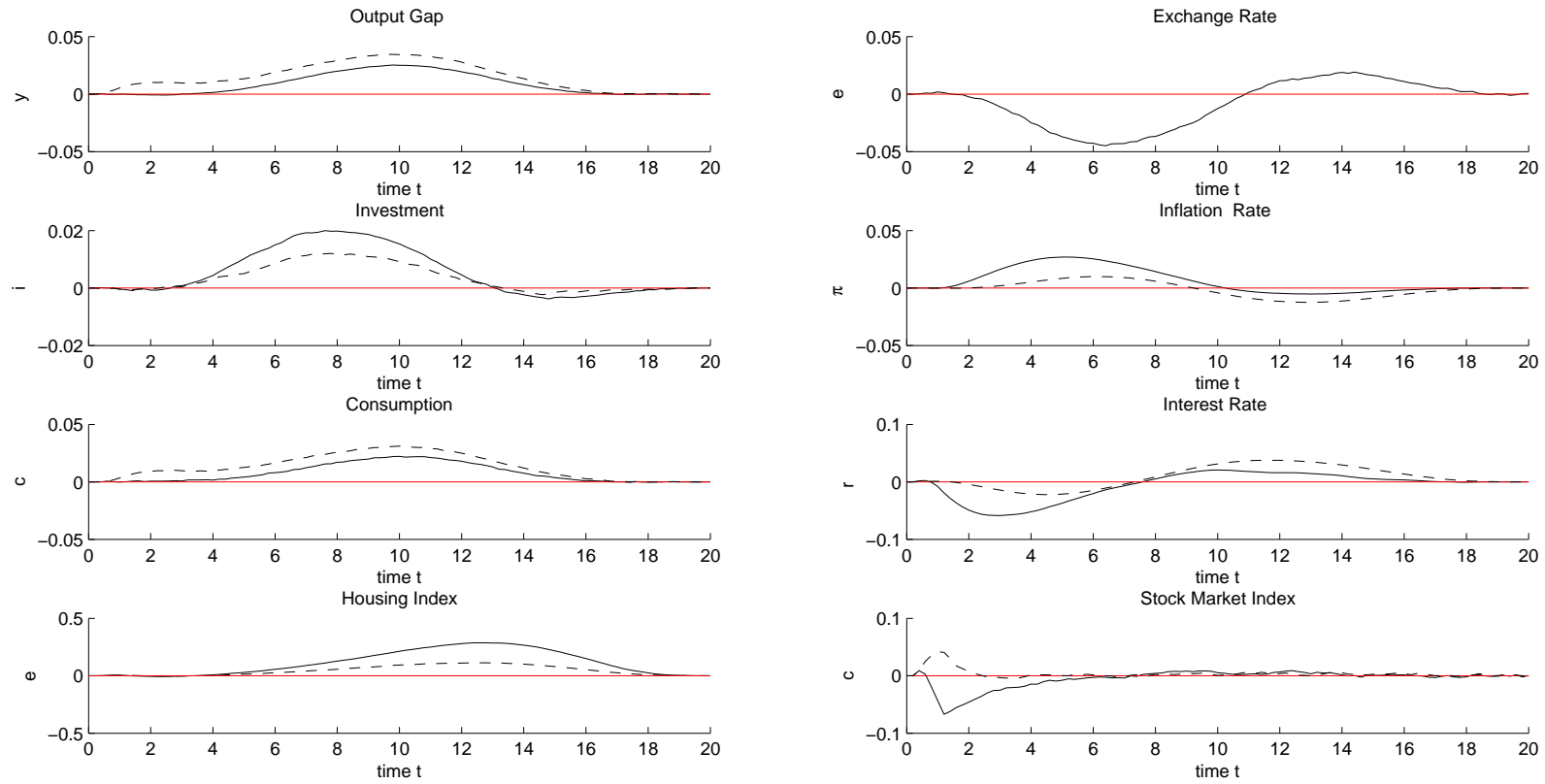


Figure IV.3.. Minor Stock Market Crisis - Standard Monetary Policy

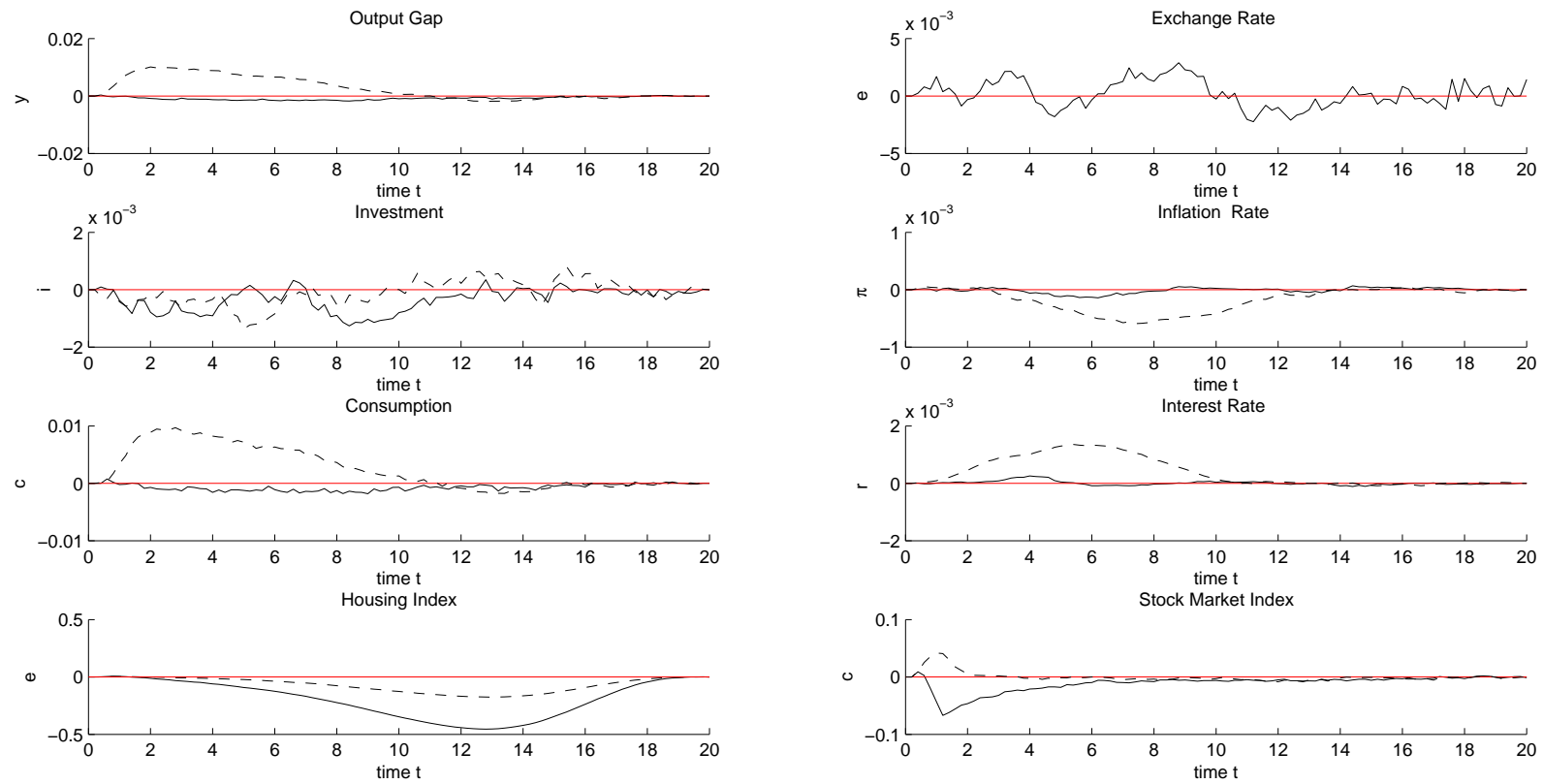


Figure IV.4.. Stock Market Crisis - Modified Monetary Policy

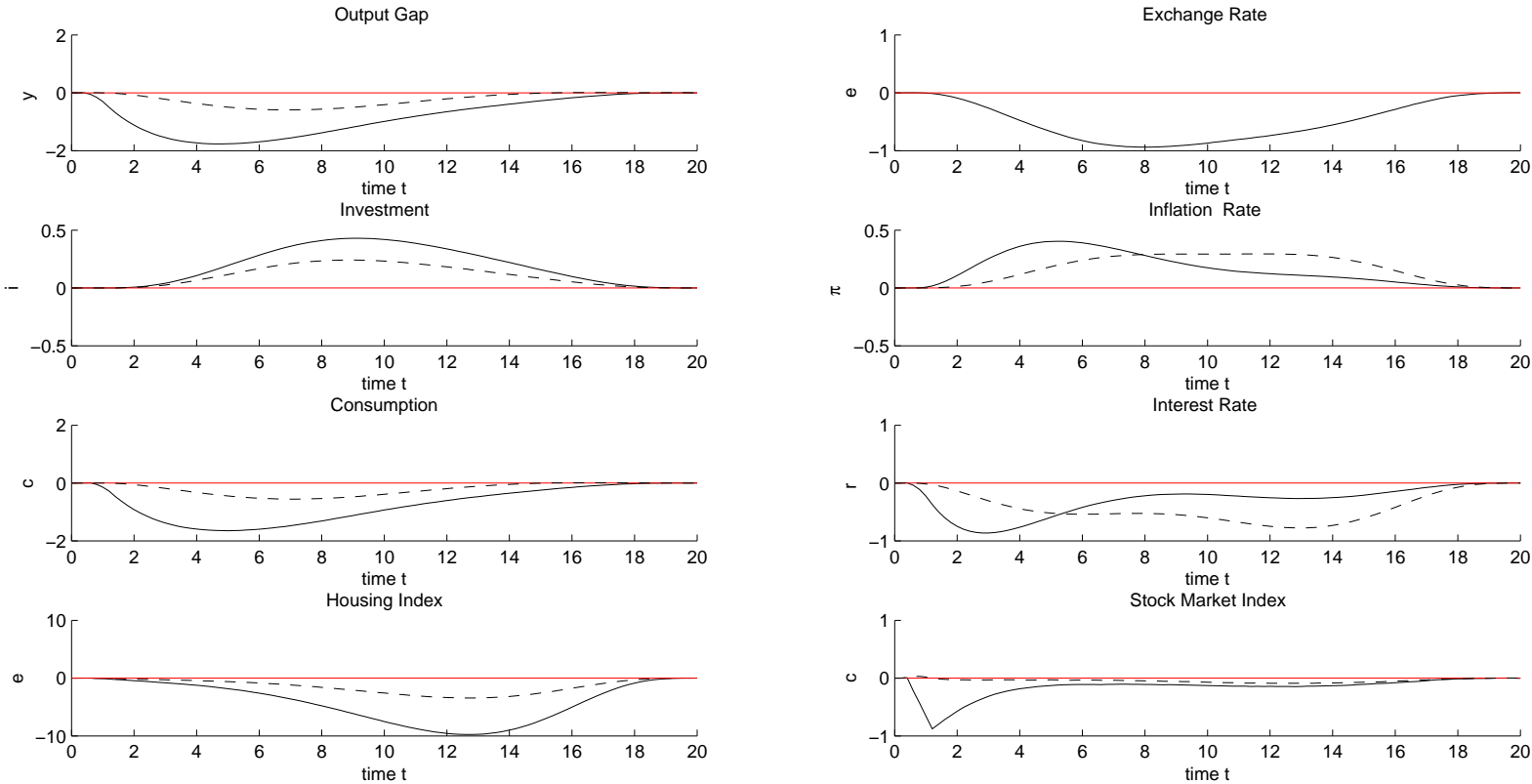


Figure IV.5.. Stock Market Crisis - Standard Monetary Policy

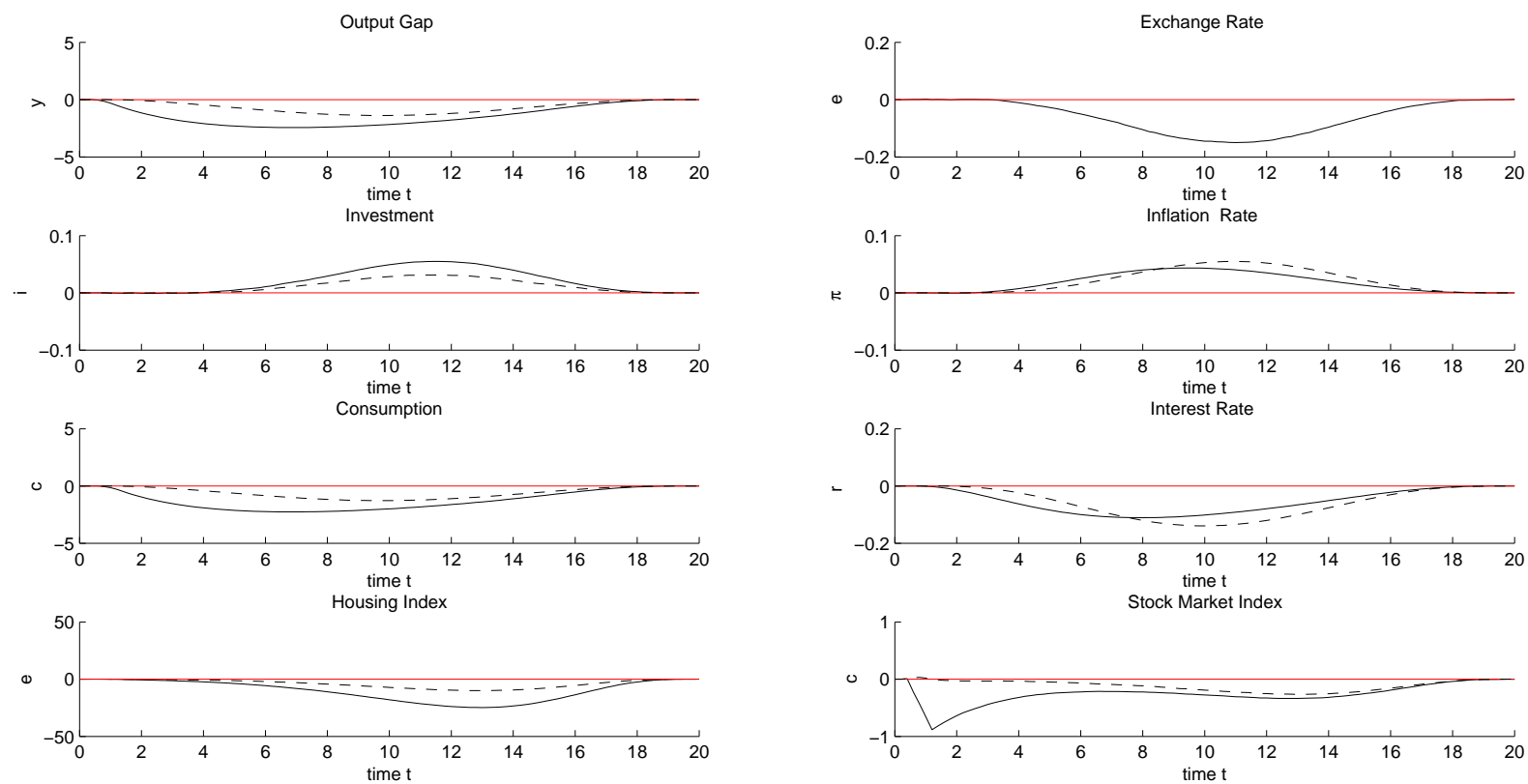


Figure IV.6.. Housing Market Crisis - Modified Monetary Policy

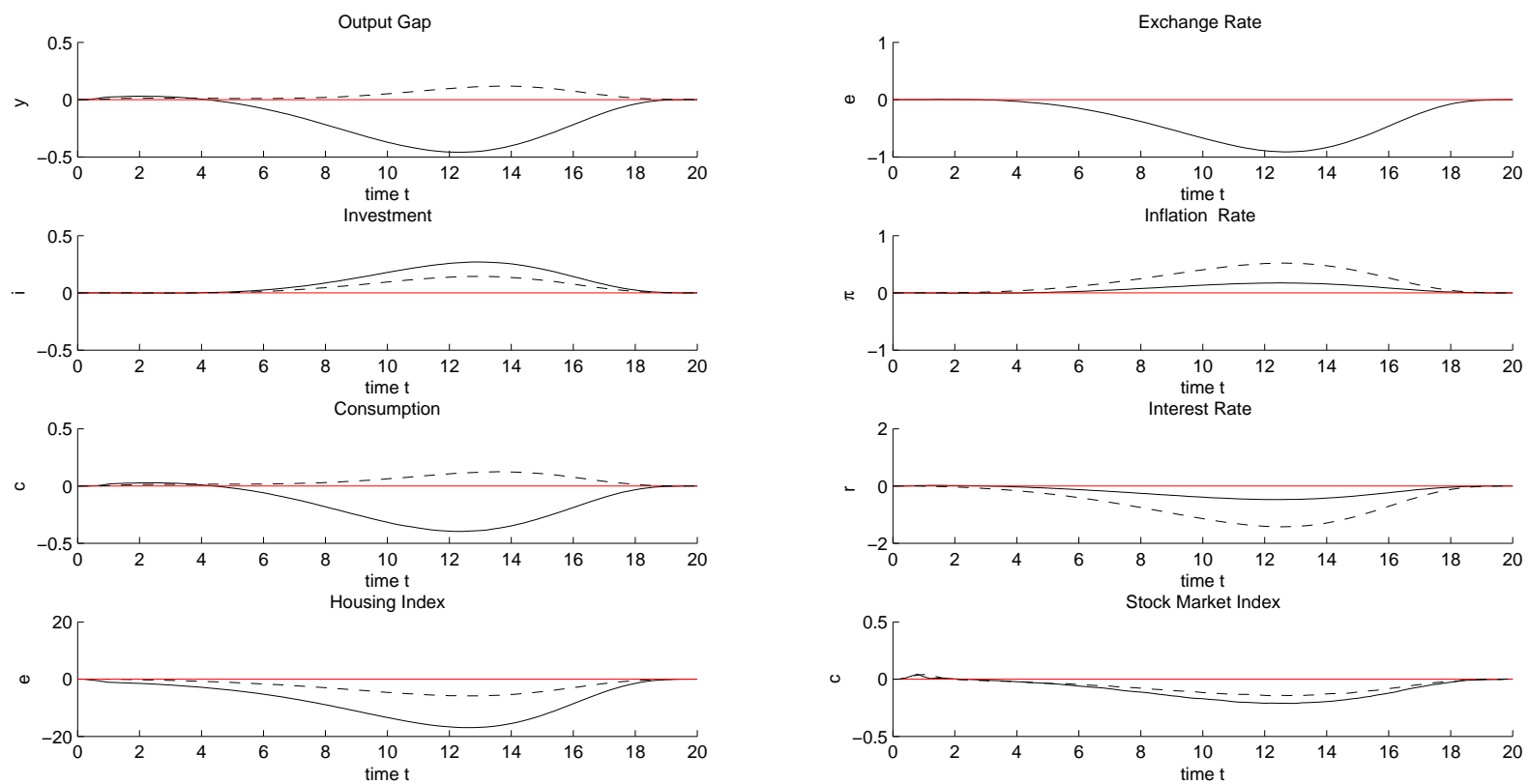


Figure IV.7.. Housing Market Crisis - Standard Monetary Policy

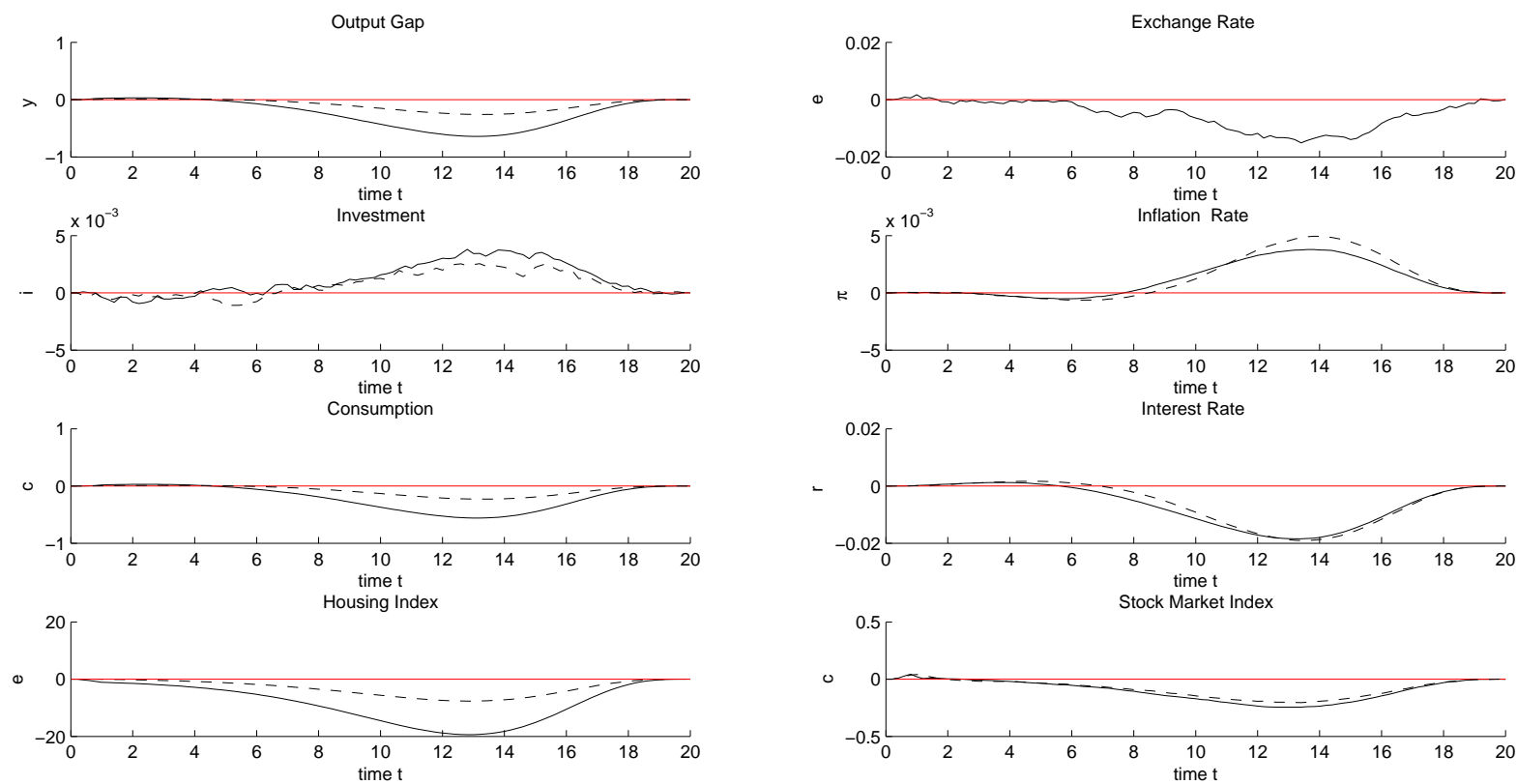


Table IV.1.. Priors and Posteriors

Variable	Parameter	Prior			Post. USA		Post. Can	
		Dist	Mean	Std	Mean	Std	Mean	Std
μ_t^{cm}	5.00	-	-	-	-	-	-	-
η_d^c	1.50	-	-	-	-	-	-	-
η_f^c	1.30	-	-	-	-	-	-	-
η^c	2.00	-	-	-	-	-	-	-
ω_f	0.75	-	-	-	-	-	-	-
μ_t^i	1.50	-	-	-	-	-	-	-
η_i	2.00	-	-	-	-	-	-	-
η_m	0.20	-	-	-	-	-	-	-
ω_i	0.80	-	-	-	-	-	-	-
μ_t^x	3.00	-	-	-	-	-	-	-
ω	0.75	-	-	-	-	-	-	-
β	0.99	Gamma	1.00	0.20	1.19	0.12	1.14	0.20
σ_c	1.20	Normal	1.50	0.50	1.24	0.11	1.23	0.50
σ_l	1.25	Normal	2.00	0.75	2.85	0.69	2.83	0.19
σ_m	1.00	Normal	1.50	0.50	1.31	0.87	1.44	0.48
h	0.97	Beta	0.70	0.10	0.72	0.36	0.71	0.20
δ	0.30	Beta	0.50	0.15	0.28	0.16	0.26	0.35
μ_t^d	0.30	Beta	0.50	0.15	0.32	0.00	0.33	0.22
α	0.20	Normal	0.30	0.10	0.24	0.00	0.24	0.56
θ	0.75	Beta	0.50	0.15	0.77	0.12	0.78	0.68
ι	0.60	-	-	-	-	-	-	-
π	1.02	Gamma	1.50	0.20	0.71	0.52	0.69	0.73
γ_n	0.50	Beta	0.50	0.15	0.44	0.00	0.39	0.32
ι_l	0.60	-	-	-	-	-	-	-
θ_h	0.68	Beta	0.50	0.15	0.79	0.61	0.78	0.48
ρ_R	0.75	Beta	0.75	0.10	0.83	0.47	0.81	1.16
ψ_{pi}	1.20	Normal	1.50	0.25	1.46	1.19	1.79	1.51
ψ_Y	0.30	Normal	0.50	0.25	0.09	0.90	0.22	0.31
ψ_h	0.10	Normal	0.50	0.25	0.25	0.31	0.23	0.22
ψ_{h^*}	0.25	Normal	0.50	0.25	0.09	0.50	0.13	0.14

ψ_s	0.10	Normal	0.50	0.25	0.24	0.60	0.23	0.27
ψ_{s^*}	0.05	Normal	0.50	0.25	0.04	0.15	0.15	0.37
ψ_{fx}	0.20	Normal	0.50	0.25	0.25	0.30	0.35	0.22
ρ_h	0.20	Normal	0.00	1.00	0.25	0.67	0.53	0.51
ρ_s	0.80	Normal	0.00	1.00	0.97	0.31	0.67	0.51
ρ_{h^*}	0.10	Normal	0.00	1.00	0.25	0.90	0.31	0.32
ρ_{s^*}	0.10	Normal	0.00	1.00	0.63	0.53	0.31	0.62
ρ_r	0.95	Normal	0.00	1.00	1.75	0.30	1.37	0.34
ρ_{r^*}	0.10	Normal	0.00	5.00	0.04	0.04	0.09	1.82
ρ_y	0.80	Normal	0.00	1.00	0.72	0.45	0.92	0.47
ρ_{fx}	0.50	Normal	0.00	1.00	0.46	0.02	0.93	2.14
ρ_{pi}	0.25	Normal	0.00	1.00	0.89	0.19	0.98	0.91
γ_h	0.80	Normal	0.00	1.00	2.37	2.01	1.34	0.22
γ_s	0.30	Normal	0.00	1.00	1.53	0.26	0.28	0.91
γ_{h^*}	0.90	Normal	0.00	1.00	1.07	2.61	0.58	1.68
γ_{s^*}	0.90	Normal	0.00	1.00	1.04	0.37	0.61	0.31
γ_r	0.90	Normal	0.00	1.00	0.99	0.79	0.85	0.99
γ_y	0.50	Normal	0.00	1.00	0.69	0.85	0.74	0.08

Table IV.2.. Extreme Values of the Simulated NK model: Maximum

Max shocks:	Modified Taylor Rule				Original Taylor Rule			
	mon. pol.	stock	bond	minor stock	mon. pol.	stock	bond	minor stock
y	0.000	0.002	0.028	0.025	0.000	0.002	0.028	0.000
y^*	0.000	0.009	0.012	0.035	0.000	0.002	0.012	0.010
S	0.537	0.001	0.003	0.019	0.396	0.002	0.004	0.003
I	0.115	0.430	0.541	0.020	0.097	0.055	0.025	0.000
I^*	0.389	0.241	0.301	0.012	0.056	0.031	0.015	0.001
π	0.000	0.404	0.598	0.027	0.000	0.043	0.032	0.000
π^*	0.536	0.295	0.747	0.010	0.000	0.055	0.029	0.000
C	0.000	0.003	0.026	0.022	0.000	0.003	0.027	0.001
C^*	0.000	0.012	0.013	0.031	0.000	0.002	0.011	0.010
R	0.942	0.002	0.021	0.021	0.940	0.000	0.001	0.000
R^*	0.235	0.000	0.000	0.038	0.000	0.000	0.001	0.001
B	0.001	0.001	0.000	0.286	0.001	0.001	0.000	0.006
B^*	0.006	0.001	0.001	0.113	0.008	0.001	0.001	0.003
N	0.083	0.009	0.041	0.009	0.044	0.009	0.041	0.009
N^*	0.082	0.032	0.040	0.042	0.081	0.032	0.040	0.042

Table IV.3.. Extreme Values of the Simulated NK Model: Minimum

Min shocks:	Modified Taylor Rule				Original Taylor Rule			
	mon. pol.	stock	bond	minor stock	mon. pol.	stock	bond	minor stock
y	-3.786	-1.766	-2.989	-0.001	-4.227	-2.439	-5.506	-0.002
y^*	-0.917	-0.592	-0.440	0.000	-1.230	-1.384	-1.515	-0.002
S	-1.231	-0.939	-1.722	-0.045	-0.001	-0.150	-0.089	-0.002
I	-0.087	0.000	-0.002	-0.004	-0.105	-0.001	-0.001	-0.001
I^*	-0.274	0.000	-0.001	-0.002	-0.255	-0.001	-0.002	-0.001
π	-0.783	0.000	-0.004	-0.005	-1.578	-0.001	0.000	0.000
π^*	-0.236	0.000	0.000	-0.012	-0.386	0.000	0.000	-0.001
C	-3.341	-1.648	-2.609	0.000	-3.864	-2.263	-4.780	-0.002
C^*	-0.770	-0.555	-0.374	0.000	-1.151	-1.275	-1.352	-0.002
R	-2.213	-0.865	-1.615	-0.059	-0.867	-0.111	-0.155	0.000
R^*	-2.077	-0.777	-2.080	-0.022	-0.506	-0.139	-0.110	0.000
B	-13.622	-9.763	-20.878	-0.007	-16.467	-24.783	-29.687	-0.455
B^*	-4.485	-3.442	-7.212	-0.003	-6.176	-9.991	-11.533	-0.176
N	-0.747	-0.877	-1.116	-0.067	-0.761	-0.883	-2.198	-0.067
N^*	-1.204	-0.090	-0.197	-0.004	-1.698	-0.265	-0.372	-0.008

Chapter V.

Monetary and Fiscal Policy in Times of Crises: A New Keynesian Perspective in Continuous Time

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Monetary and Fiscal Policy in Times of Crises: A New Keynesian Perspective in Continuous Time

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Abstract

To analyse the interdependence between monetary and fiscal policy during a financial crisis, we develop an open-economy DSGE model with monetary and fiscal policy as well as financial markets in a continuous-time framework based on stochastic differential equations. Monetary policy is modelled using both a standard and a modified Taylor rule and fiscal policy is modelled as either expansionary or austere. In addition, we differentiate between open economies and monetary union members. We find evidence that the modified Taylor rule notably reduces the likelihood that the financial market crisis affects the real economy. But if we assume that households are averse with respect to outstanding government debt, we find that a combination of expansionary monetary policy and austere fiscal policy provides better stabilisation of both domestic and foreign economies in terms of both output and inflation. In the case of a monetary union, we find that stabilisation of output in the country where the financial shock originates is no longer as easy and, in terms of prices, there is now deflation in the country where the crisis originated and a positive inflation rate in the other country.

KEYWORDS: New Keynesian Models, Financial Crisis, Dynamic Stochastic General Equilibrium Models, Continuous Time Model, Fiscal Policy, Monetary Policy

JEL CLASSIFICATION: C63, E44, E47, E52, E62, F41

V.1. Introduction

Advances in globalisation, economic integration, and information technology have had, and continue to have, a profound effect on national economies. First, modern economies are characterised by unprecedented levels of openness with respect to trade and international capital flows. Although this has the benefit of resulting in an efficient allocation of resources, it also makes national economies more vulnerable to shocks originating in other countries. Second, market news, as well as economic policy news, happens more quickly and more frequently than ever before and economic activity is nearly continuous (Bergstrom and Nowman 2007). For example, the share of high-frequency trading grew from less than 10% in the early 2000s to more than 40 – 50% today (Curdia and Woodford 2008). Third, many advanced economies are characterised by a high degree of integration between their financial and real sectors. The interdependency between financial market stability and macroeconomic stability is clearly illustrated by the recent financial crisis. Fourth, following right on the heels of the financial crisis, the European debt crisis makes clear that a monetary union with a common monetary policy but national fiscal policies generates new economic interdependencies and highlights the linkages between monetary and fiscal policies. Given that there has not been a debt crisis outside the European Monetary Union, the question arises as to whether transformation of financial market shocks within a monetary union is different from what occurs in open economies that continue to have autonomy over their interest and exchange rates. Finally, the use of stabilisation policy, for instance, to contain an economic crisis, generates spillovers to other countries, a fact often ignored in the economic literature.

Discrete-time frameworks are frequently used in theoretical macroeconomic analyses. However, Yu (2013) provides strong reasons for why continuous-time models should be preferred, as the economy is evolving continuously although time is only measured in discrete steps' (Bartlett 1946). Especially in models containing financial markets, a continuous time perspective may lead to a better approximation of the actual dynamics of economic behaviour. Another important advantage of continuous-time models is that they provide a convenient mathematical framework that allows researchers to price financial assets in an analytically tractable way. Moreover, continuous-time models allow treating stock and flow variables separately, which has the added advantage of making it possible to conduct a mathematical stability analysis (Thygesen 1997), which is often ignored in discrete-time macroeconomic models. Therefore, we rely on previous analyses of Brunnermeier and Sannikov (2012) and Hayo and Niehof (2013a, 2014) and build continuous-time models that allow for greater volatility in financial markets and a thorough modelling of the term structure of interest rates.

In the extant literature on the influence of the financial sector on the macroeconomy, most studies use techniques from either finance (Bianchi, Pantanella and Pianese 2013) or macroeconomics (Aït-Sahalia,

Cacho-Diaz and Laeven 2010; Bekaert, Hoerova and Lo Duca 2013; El-Khatib, Hajji and Al-Refai 2013; Gertler and Karadi 2011; Gertler, Kiyotaki and Queralto 2012) but a fully-fledged combination of the two approaches has not yet been undertaken. Brunnermeier and Sannikov (2012) provides a detailed literature overview of the latter research strand. In contrast, we synthesise both approaches by combining a macroeconomic dynamic stochastic general equilibrium model (DSGE) with a stochastic volatility model.¹ Our goal is a better understanding of the effects of financial market shocks on the real economy under different types of stabilisation policy. Hence, we analyse combinations of fiscal and monetary policy reactions to domestic and foreign financial market shocks. We develop a New Keynesian DSGE model of two open economies based on stochastic differential equations. Within this framework, we can analyse spillover effects between financial markets as well as contagion from financial markets to the real economy, both within and across economies. We then study various stabilisation policy scenarios. These include (1) a standard open-economy Taylor rule that focuses on stabilising output, inflation, and the exchange rate; (2) a modified Taylor rule that additionally takes into account financial market stabilisation; (3) an expansionary expenditure-based fiscal policy; and (4) an austere fiscal policy. In addition, we differentiate between market participants who are neutral with respect to high government debt and those who are debt averse.

We argue that academic research can aid policymakers by analysing the extent to which financial markets should be taken into consideration when designing stabilisation policy. In our approach, we explore the consequences of taking seriously the interaction between financial markets, stabilisation policy, and the real economy in a two-country, open-economy framework based on a fully dynamic theoretical model.

Our paper makes several contributions to the literature. First, we combine and extend the models of Smets and Wouters (2002) and Bekaert, Cho and Moreno (2010) and compute a New Keynesian model with fiscal and monetary policy, including a financial market sector. Derivation of the monetary policy rule is in line with Ball (1998); specifically, we employ the nominal interest rate and the exchange rate as monetary policy targets in an open economy. Moreover, we follow Bekaert, Cho and Moreno (2010) and Brunnermeier and Sannikov (2012) and model a financial market sector, which allows for the consistent inclusion of financial markets in the policy rule. Faia and Monacelli (2007) provide empirical evidence that financial market variables in the Taylor rule have a significant impact on actual decision-making processes. In a similar vein, Belke and Klose (2010) estimate Taylor rules for the European Central Bank (ECB) and the Federal Reserve (Fed) and include asset prices as additional monetary policy targets. For

¹ Stochastic volatility models are a class of models in which the variance of a stochastic process is itself randomly distributed. They are widely used in finance. A famous representative of these models is the Heston model, which is used to describe asset evolution and which overcomes the shortcomings of the standard Black Scholes model

our fiscal rules, we distinguish between an expansionary expenditure policy and fiscal austerity, which, to some extent, reflects current discussion in Europe, where southern European countries as well as France favour the former, and Germany and the United Kingdom prefer the latter.

In that financial markets are characterised by a substantial degree of simultaneity, our second contribution is to incorporate several interdependent financial markets in our model, i.e., markets for bonds and stocks. Empirical evidence for financial market simultaneity is presented by Bjornland and Leitemo (2009a), Rigobon (2003) and Rigobon and Sack (2003b)². In light of this work, we include both markets in the modified monetary policy rule, which implies a stronger monetary policy response in the event of a general financial market crisis than would be the case if only one financial market showed crisis symptoms. Moreover, we study scenarios assuming either that households, who also act as financial market participants in our model, do not care about the number of bonds issued by the government or have a negative reaction to debt.

As our third contribution, we combine finance research with macroeconomic theory by employing a continuous-time framework as introduced by Hayo and Niehof (2013a). This allows the use of advanced techniques from the finance literature, such as jump-diffusion processes, to model financial markets. Technically, we transform the New Keynesian model into stochastic differential equations and compute solutions by using advanced numerical algorithms. We believe that forging this link between methods from economics, finance, and mathematics is a unique and valuable contribution.

The remainder of the paper is structured as follows. Section 2 derives the theoretical model. Section 3 shows how the model is shifted to a continuous-time framework. Section 4 contains the model calibration. Section 5 studies the effects of financial market turmoil using dynamic simulations. Section 6 concludes.

V.2. The Model

To study the effects of financial crisis under different types of stabilisation policy, we employ the extended New Keynesian short-term model developed by (among others) Ball (1998) and Clarida, Gali and Gertler (1999, 2000, 2002). To account for globalisation, we extend the analysis to a two-country, open-economy world. Fiscal policy is modelled by debt-financed changes in government expenditure; monetary policy by changes in the nominal interest rate. As our chief interest is short-term reactions in times of crises, we neglect tax effects and concentrate on government expenditure. However, we account for the financing side of expenditure policy by including the impact of higher public debt on the bond-pricing equation. Our model combines many features from the models of Ball (1998), Lindé, Nessén and

² A theoretical discussion is provided by Hildebrand (2006).

Söderström (2009) and Smets and Wouters (2002, 2007).

V.2.1. The Demand Side

Domestic households consume bundles of both domestic and imported goods. All goods have a domestic and foreign currency price index P_t^d and P_t^f respectively. For the sake of simplicity, we assume perfect pass-through (in contrast to Lindé, Nessén and Söderström (2009)); that is, domestic and foreign prices coincide. and argue that domestic and foreign prices coincide. This implies that the exchange rate S_t is the ratio between domestic and foreign aggregate price levels

$$S_t = \frac{P_t^f}{P_t^d}. \quad (\text{V.1})$$

Households

Households are assumed to exist in perpetuity and they consume Dixit-Stiglitz bundles of domestic and imported goods C_t^d and C_t^m (Dixit and Stiglitz 1977). The bundles of domestic and imported goods are defined by

$$C_t^d = \left[\int_0^1 (C_t^d(i))^{\frac{\eta_d^c-1}{\eta_d^c}} di \right]^{\frac{\eta_d^c}{\eta_d^c-1}} \quad (\text{V.2})$$

$$C_t^f = \left[\int_0^1 (C_t^f(i))^{\frac{\eta_f^c-1}{\eta_f^c}} di \right]^{\frac{\eta_f^c}{\eta_f^c-1}} \quad (\text{V.3})$$

where η_d and η_f are the elasticities of substitution across goods, assumed to be greater than one to ensure that firm i 's mark-ups are positive in the steady state. In total, domestic and imported goods form a composite index such that

$$C_t = \left[(1 - \omega_f)^{\frac{1}{\eta_c}} (C_t^d)^{\frac{\eta_c-1}{\eta_c}} + \omega_f^{\frac{\eta_c-1}{\eta_c}} S_t (C_t^f)^{\frac{\eta_c-1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c-1}} \quad (\text{V.4})$$

where ω_f is the share of imports in consumption, and η_c is the elasticity of substitution across the two categories of goods. Accordingly, the aggregate consumer price index (CPI) is given by

$$P_t = \left[(1 - \omega_f)(P_t^d)^{1-\eta_c} + \omega_f(P_t^f)^{1-\eta_c} \right]^{\frac{1}{1-\eta_c}} \quad (\text{V.5})$$

Similarly, households invest either domestically or abroad. The share of exported investments of the

domestic country is denoted by ω_{f_2} and the nominal exchange rate by $S_t(\cdot)$. Therefore

$$I_t^d = \left[\int_0^1 (I_t^d(i))^{\frac{\eta_d^i-1}{\eta_d^i}} di \right]^{\frac{\eta_d^i}{\eta_d^i-1}} \quad (\text{V.6})$$

$$I_t^f = \left[\int_0^1 (I_t^f(i))^{\frac{\eta_f^i-1}{\eta_f^i}} di \right]^{\frac{\eta_f^i}{\eta_f^i-1}} \quad (\text{V.7})$$

$$I_t = \left[(1 - \omega_{f_2})(I_t^d) + \omega_{f_2}S_t(I_t^f) \right] \quad (\text{V.8})$$

Households decide on today's consumption by taking into account past aggregate consumption. Household j 's utility depends positively on the fraction of its own consumption C_t^j in proportion to lagged aggregate consumption C_t and negatively on labour N_t^j . Furthermore, a household can purchase government securities $V_{t,t+m}$. In total, household j maximises its utility by choosing the optimal combination of consumption and labour supply.

$$u(C_t^j, N_t^j) = \left[\frac{(C_t^j - hC_{t-1}^j)^{1-\sigma}}{1-\sigma} - \frac{\epsilon_L}{1+\sigma_L} (N_t^j)^{1+\sigma_L} \right] \quad (\text{V.9})$$

where $0 \leq h \leq 1$ is the component of habit formation as proposed in Abel (1990) and Fuhrer (2000), and $\sigma > 0$ is related to the intertemporal elasticity of substitution. Wages are set subsequently. The household's objective is to maximise expected discounted life-time utility

$$\max E_t \sum_{k=0}^{\infty} \beta^k u(C_{t+k}^j, N_{t+k}^j) \quad (\text{V.10})$$

subject to the following budget constraint

$$\begin{aligned} & \frac{W_t^i}{P_t} N_t^j + R_t^k Z_t^j K_{t-1}^j - a(Z_t^j) K_{t-1}^j - \frac{B_t^j R_t^{-1} - B_{t-1}^j}{P_t} - \frac{(V_t^E Equ_t^i - V_{t-1}^E Equ_{t-1}^i)}{P_t} \\ & - \frac{S_t(B_t^j)^*(R_t^*)^{-1} - S_t(B_{t-1}^j)^*}{\Phi_2(S_t, B_t, P_t)P_t} - C_t - I_t^j - A_t^j - T_t + \frac{Div_t}{P_t} Equ_{t-1}^j \\ & - \frac{(S_t(V_t^E)^*(Equ_t^j)^* - S_t(V_{t-1}^E)^*(Equ_{t-1}^j)^*)}{\Phi_2(S_t, V_t, P_t)P_t} - \sum_{j=0}^J \left(\frac{V_{t,t+m}^B}{P_t} B_{t,j}^j - \frac{V_{t-1,t+m-1}^B}{P_t} B_{t-1,t+m}^j \right) \\ & - \sum_{j=0}^J \left(S_t \frac{(V_{t,t+m}^B)^*}{\Phi_2(S_t, V_t, P_t)P_t} (B_{t,t+m}^j)^* - S_t \frac{(V_{t,t+m-1}^B)^*}{\Phi_2(S_t, V_t, P_t)P_t} (B_{t-1,t+m}^j)^* \right) \\ & + \frac{S_t Div_t^*}{P_t} (\Phi_2(S_t, Equ_t^j, P_t) Equ_{t-1}^j)^* = 0 \end{aligned} \quad (\text{V.11})$$

where R_t is the domestic interest rate, R_t^f is the foreign interest rate, B_t and B_t^f are holdings of nominal bonds, X_t^j is the household's share of aggregate real profits in the domestic economy, $Equi_t$ are firm's equities and T_t are lump-sum taxes. $A_t \equiv \frac{S_t B_t^f}{P_t}$ is the net foreign asset position of the domestic economy. As in Benigno (2009), the term $\Phi_2(\cdot)$ captures the costs for domestic households of participating in international financial markets. These costs are assumed to follow $\Phi_2(W_t) = e^{-\phi W_t}$ where $\phi > 0$. Thus, if the domestic economy is a net borrower, domestic households are charged a premium on the foreign interest rate.

Total income evolves as

$$Y_t^j = (W_t^j N_t^j + A_t^j) + (R^k Z_t^j K_{t-1}^j - \Psi(Z_t^j) K_{t-1}^j) + Div_t^j$$

where $W_t^j N_t^j + A_t^j$ is labour income plus securities, $r^k z_t^j K_{t-1}^j - \Psi(Z_t^j) K_{t-1}^j$ is the return on capital minus costs and Div_t^j are dividends. We assume $\Psi(1) = 0$ reflects the situation that the capital utilisation rate Z_t is one in the steady state.

Consumption

The maximisation problem described previously yields the consumption Euler equation (where λ_t is the Lagrangian parameter)

$$E_t \left[\beta \left(h \frac{(C_{t+1}^j - h C_t^j)^{-\sigma}}{(C_t^j - h C_{t-1}^j)^{-\sigma}} \right) \frac{(1 + R_t) P_t}{P_{t+1}} \right] = 1 \quad (\text{V.12})$$

Furthermore, this implies the uncovered interest rate parity (UIP) condition

$$1 = E_t \frac{S_{t+1}}{S_t} \Phi_2(W_t) \quad (\text{V.13})$$

In the case where the domestic economy is a net borrower, $\Phi_2(W_t)$ implies that the domestic interest rate is higher than the foreign interest rate. Therefore, movements in an economy's asset position imply changes in the exchange rate.

Domestic and imported goods are allocated optimally

$$\begin{aligned} C_t^d &= (1 - \omega_x) \left[\frac{P_t^d}{P_t} \right]^{-\eta_c} C_t \\ C_t^f &= S_t \omega_f \left[\frac{P_t^f}{P_t} \right]^{-\eta_c} C_t \end{aligned}$$

Households own the capital stock, which they lend to producers of (intermediate) goods at a rental

rate R_t^k . Households can either raise additional capital I_t or change the utilisation rate of existing capital Z_t . As households are restricted by their intertemporal budget constraint, both actions are costly in terms of forgone consumption. Furthermore, households choose investment, and utilisation rates so as to maximise their intertemporal objective function, subject to the intertemporal budget constraint and the capital accumulation equation, which is given by

$$K_t = K_{t-1}(1 - \delta) + \left(1 - V\left(\frac{I_t}{I_{t-1}}\right)\right) I_t \quad (\text{V.14})$$

where δ is the depreciation rate, and $V(\cdot)$ is an adjustment cost function. We assume that V is zero in the steady state and that the first derivative is zero around the steady state too, so that the adjustment costs only depend on the second-order derivative: $V'(1) = V(1) = 0$ and $V''(1) > 0$

To specifically differentiate between real capital and financial assets, we exclude a firm's value, denoted in assets, from our definition of capital and incorporate the assets into a separate financial sector (see below). However, these assets are part of the aggregate demand.

V.2.2. The Supply Side

Firms

Both domestic and foreign firms are subject to monopolistic competition. However, imported goods are traded in a different market than domestic products and are imported by domestic firms. The final good is produced using the following production function

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \quad (\text{V.15})$$

Firms profits are immediately paid out as dividends

$$\frac{Equ_{t-1}^j Div_t^i}{P_t} = \frac{P_t^i}{P_t} Y_t^j - \frac{W_t}{P_t} N_t^i - R_t^k \tilde{K}_t^i \quad (\text{V.16})$$

The intermediate good is produced under monopolistic competition using the Cobb-Douglas production function

$$Y_t(i) = A_t K_t(i)^\alpha N_t(i)^{1-\alpha}.$$

Prices are set according to the Calvo pricing mechanism (Calvo 1983). A fraction θ of firms exhibit 'rule of thumb' price-setting behaviour, which is modelled as

$$P_t(i) = P_{t-1}(i). \quad (\text{V.17})$$

The other fraction of the firms $1 - \theta$ optimise their prices in consideration of their discounted profits

$$E_t \sum_{l=0}^{\infty} \beta^l \theta^l v_{t+l} (P_{t+l}(i) Y_{t+l}(i) - W_{t+l} N_{t+l}(i) - R_{t+l}^k K_{t+l}(i)) \quad (\text{V.18})$$

where v_t is the multiplier of the household budget constraint in the Lagrangian representation. Firms maximise their profits subject to Calvo pricing, their production technology, and the demand for good $Y_t(j)$

$$Y_t(j) = \left(\frac{P_t}{P_t(j)} \right)^\epsilon Y_t \quad (\text{V.19})$$

V.2.3. Wage Setting

Each household sells his labour due to the production function

$$N_t = \left(\int_0^1 (N_t^j)^{\frac{1}{\gamma_n}} \right)^{\gamma_n} \quad (\text{V.20})$$

where γ_n is the wage mark-up and $1 \leq \gamma_n < \infty$. Similarly to the firm's problem households face a random probability $1 - \theta_h$ of changing nominal wage. The j^{th} household reoptimised wage is \overline{W}_t^j , whereas the unchanged wage is given by $W_{t+1}^j = W_t^j \pi_t^{\iota_h} \pi^{1-\iota_h} \mu_z$, where μ_z is the technological growth rate $\frac{z_{t+1}}{z_t}$. Households then maximise their optimal wage subject to the demand for labour and the budget constraint.

$$N_{t+s}^i = \left(\frac{\overline{W}_t^i \prod_{l=1}^s (\pi_{t+l-1}^{\iota_h} \pi^{1-\iota_h} \mu_z)}{W_{t+s}} \right)^{\frac{\gamma_n}{1-\gamma_n}} N_{t+s} \quad (\text{V.21})$$

Wages therefore evolve as

$$W_t = \left[\theta_h \left(W_{t-1} \pi_{t-1}^{\iota_h} \pi^{1-\iota_h} \mu_z \right)^{\frac{1}{1-\gamma_n}} + (1 - \theta_h) \overline{W}_t^{\frac{1}{1-\gamma_n}} \right]^{1-\gamma_n} \quad (\text{V.22})$$

V.2.4. The Exchange Rate and the Uncovered Interest Rate Parity

In line with Ball (1998), Lindé, Nessén and Söderström (2009) and Batini and Nelson (2000), the exchange rate is a function of the nominal interest rate and inflation. The uncovered interest rate (UIP) condition states that

$$\frac{1 + R_t}{1 + R_t^f} = E_t \left[\frac{S_{t+1}}{S_t} \right] \Phi_2(W_t) \quad (\text{V.23})$$

To explicitly analyse exchange rate bubbles, we follow Batini and Nelson (ibid.) and add another shock variable φ to reflect the potential burst of a bubble. A detailed description of the computation, length and values of the additional variable is provided by Batini and Nelson (ibid.).

$$\frac{1 + R_t}{1 + R_t^f} = E_t \left[\frac{S_{t+1}}{S_t} \right] \Phi_2(W_t) \varphi_t \quad (\text{V.24})$$

Tobin's Q is given by $Q_t^i = \frac{\varphi_t^i}{\lambda_t^i}$ in

$$Q_t^i = \beta E_t \left(\frac{\lambda_{t+1}^i}{\lambda_t^i} \left(R_t^k Z_t^i - a(Z_t^i) \right) + Q_{t+1}^i (1 - \delta) \right) \quad (\text{V.25})$$

V.2.5. Financial Sector

There are various ways of integrating financial variables into macroeconomic models. Gertler, Kiyotaki and Queralto (2012) apply a micro-based model and incorporate a banking sector and financial frictions. However, we are focussing on asset market spillovers to the real economy and are thus less interested in analysing financial intermediaries. Brunnermeier and Sannikov (2012) construct a macroeconomic model with an emphasis on variations in risk preferences and the degree of information across households and financial experts. However, since the authors do not model real economic effects, their framework is not well-suited to our focus on financial and macroeconomic spillovers under different stabilisation policies. Instead, we extend the NK framework of Paoli, Scott and Weeken (2010b) by defining different term structures and rigidities and moving the analysis to an open-economy setting. We also follow Bekaert, Cho and Moreno (2010) and Paoli, Scott and Weeken (2010b) and model financial market returns first in discrete time and then switch to continuous time. In the absence of frictions, the model exhibits the well-known equity and term premia puzzle. As demonstrated by Campbell and Cochrane (1999) in the context of endowment economies, consumption habits can be used to solve this puzzle. By switching off capital adjustment costs, we confirm the results of Boldrin, Christiano and Fisher (2001) that, in a production economy, consumption habits by themselves do not suffice to remove the puzzles.

In fact, consumer-investors can adjust their capital stock and alter production plans.

The presence of state-contingent claims implies that we can price all financial assets in the economy based on no-arbitrage arguments. Hence, the price of a zero-coupon bond is given by the first-order conditions (FOCs). We follow Binsbergen, Fernandez-Villaverde, Koijen and Rubio-Ramírez (2012) and Paoli, Scott and Weeken (2010b) and model the term structure recursively. The one-period nominal bonds deriving the standard relationship are given by

$$\frac{1}{R_t} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \varphi_t^B \quad (\text{V.26})$$

$$\frac{1}{R_t^*} = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \frac{S_{t+1}}{S_t} \right] \varphi_t^{B^*} \quad (\text{V.27})$$

where φ_t^B is a shock to a one-period nominal bond and λ_t is the Lagrangian from the household's FOCs

$$\lambda_t = \epsilon_t^U (C_t^i - hC_t - 1^i)^{-\sigma_c} - \beta h E_t [\epsilon_{t+1}^U (C_{t+1}^i - hC_{t+1}^i)^{-\sigma_c}]$$

A real zero-coupon bond returns one unit of consumption at maturity. For $m = 1$ it is

$$-\lambda_t \frac{V_{t,1}^B}{P_t} = E_t \left[\beta \lambda_{t+1} \frac{V_{t+1,0}}{P_{t+1}} \right] \varphi_t^V \quad (\text{V.28})$$

$$\Leftrightarrow V_{t,1}^B = E_t \left[-\beta V_{t+1,0} \frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \varphi_t^V \quad (\text{V.29})$$

$V_{t+1,1}$ is the price of a bond of original maturity $m = 2$ with one period left. Assuming no arbitrage, this price equals the price of a $j = 1$ bond issued next period. Bond prices can thus be defined recursively (using $SDF_t = \beta \frac{\lambda_{t+1}}{\lambda_t}$)

$$V_{t,t+m}^B = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} V_{t+1,t+m-1}^B \frac{P_t}{P_{t+1}} \right] \varphi_t^V \quad (\text{V.30})$$

$$= E_t (SDF_{t+1} \pi_{t+1} V_{t+1,t+m-1}^B) \varphi_t^V \quad (\text{V.31})$$

Assuming $V_{t,1} = 1$ in terms of one unit of consumption, we apply recursion and obtain

$$V_{t,t+m}^B = E_t ((SDF_{t+1} \pi_{t+1})^m) \quad (\text{V.32})$$

Real yields are then given by

$$R_{t+1,t+m}^B = (V_{t,t+m}^B)^{-\frac{1}{m}} \quad (\text{V.33})$$

Similarly, it is

$$V_{t,t+m}^{B*} = E_t \left[-\beta \frac{\lambda_{t+1}}{\lambda_t} (V_{t+1,t+m-1}^B)^* \frac{P_t}{P_{t+1}} \right] \varphi_t^{V^*} \quad (\text{V.34})$$

$$R_{t+1,t+m}^{B*} = ((V_{t,t+m}^B)^*)^{-\frac{1}{m}} \quad (\text{V.35})$$

Regarding the assets, we derive

$$1 = E_t \left[-\beta \frac{P_t}{P_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} \frac{V_t^E + \text{Div}_{t+1}}{V_t^E} \right]$$

with real return

$$R_{t+1}^E = \frac{V_t^E + \text{Div}_t}{V_t^E} \frac{P_t}{P_{t+1}}$$

Andreasen (2012), Andreasen (2010) and Wu (2006) show that this specification is equivalent to standard finance models, such as Dai and Singleton (2000), Duffie and Kan (1996) and Duffie, Pan and Singleton (2000).

V.2.6. Fiscal and Monetary Policy Authorities

We take a look at different types of stabilisation policies. Regarding fiscal policy, the tax rule is derived from the government's budget constraint (Kirsanova and Wren-Lewis 2012; Schmitt-Grohé and Uribe 2007). Each period, the government collects tax revenues T_t and issues m -period nominal bonds $V_{t,t+m}^B$ to finance its interest payments and expenditure including government consumption G_t . The fiscal authority has two objectives: output stabilisation and debt stabilisation. We follow Çebi (2012), Favero and Monacelli (2005), Kirsanova and Wren-Lewis (2012) and Muscatelli, Tirelli and Trecroci (2004) and employ a smoothed fiscal government spending rule based on the evolution of debt

$$G_t = G_{t-1}^{\varsigma_G} (Y_{t-1}^{\varsigma_Y} V_{t,t+m}^{s_b} \epsilon_t^G)^{1-\varsigma_G} \quad (\text{V.36})$$

$$T_t = T_{t-1}^{\varsigma_T} (Y_{t-1}^{\varsigma_{YT}} V_{t,t+m}^{s_{b_T}} \epsilon_t^T)^{1-\varsigma_T} \quad (\text{V.37})$$

where ς_G and ς_T are the degree of fiscal smoothing, and ς_Y , ς_{YT} , s_b , s_{b_z} specify the government's reaction to last period's income and bonds. ϵ_t^G and ϵ_t^T are hocks that cause actual government expendit-

ure and revenue, respectively, to deviate from the plans. Different degrees of fiscal smoothing lead to different changes in the responsiveness of spending and tax with respect to debt income, which can be interpreted as an output gap. For example, an increase in the degree of fiscal smoothing results in a declining sensitivity of government spending and tax to income and debt. Both fiscal rules are ad-hoc rules and reflect our assumption that governments have no borrowing constraints in the short run. This is in line with Leith and Von Thadden (2008), who develop a tractable NK model where government debt is not subject to a budget constraint.

For the monetary policy rule, we follow Ball (1998), Justiniano, Primiceri and Tambalotti (2010), Leitemo and Soderstrom (2005), Lubik and Schorfheide (2007), Lubik and Smets (2005), Smets and Wouters (2007), Svensson (2000b) and Taylor (1993) and employ an open-economy Taylor rule taking into account output, inflation, and the exchange rate. In an extension of this standard Taylor rule, we construct a second monetary policy reaction function that also takes into account financial market developments.

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi_{t-1}} \right)^{\psi_P} \left(\frac{S_t}{S_{t-1}} \right)^{\psi_S} \left(\frac{R_t^E}{R_{t-1}^E} \right)^{\psi_E} \right]^{1-\rho_E} \eta_{mp,t} \quad (\text{V.38})$$

represents the financial sector, which is comprised of bond and stock markets, and $\eta_{mp,t}$ is a monetary policy shock.

$$\log \eta_{mp,t} = \rho_{mp,t} \log(\eta_{mp,t-1}) + \epsilon_{mp,t} \quad (\text{V.39})$$

where $\epsilon_{mp,t}$ is *i.i.d.* $N(0, \sigma_{mp}^2)$. Thus, our modified Taylor rule accounts for domestic and foreign output, the exchange rate, inflation, and the financial market. The rule facilitates an analysis of spillover effects between financial markets and monetary policy as well as between foreign and domestic policy. Moreover, by including the financial sector, which consists of various markets, we account for a direct relationship between monetary policy and financial markets. Rigobon (2003) and Rigobon and Sack (2003b) show empirically that including this aspect is useful.

V.2.7. Market Clearing

In the specific analysis of financial markets, we treat equities and bonds as financial instruments and assign them to a new sector, the financial market. A shortcoming of this way of modelling a financial sector is that it does not directly contribute to the economy's value-added as it only addresses allocational aspects. However, as is common in the finance literature, we model financial instruments stochastically. For simplicity reasons, we focus on the allocational purpose of financial markets. However, in principle,

the introduction of a banking sector or entrepreneurs would easily allow for an extension of the financial sector's role in the economy.

In our simple framework, markets clear as

$$Y_t = C_t^d + C_t^f + I_t^d + I_t^f + FM_t^d + FM_t^f + a(Z_t)K_{t-1} + G_t \quad (\text{V.40})$$

where FM_t is the financial sector.

V.2.8. The Special Case of a Monetary Union

As we are also interested in analysing the case of a monetary union, we model a monetary union characterised by a constant exchange rate and the same interest rate resulting from the common monetary policy rule. As we assume a perfect pass-through, the terms of trade equal the exchange rate, which is one, and this implies that purchasing power parity holds. To reflect the supranational central bank's position, we use the average rate of inflation and the average output gap of both economies in the Taylor rule. A full model derivation is provided by Fahr and Smets (2010).

V.3. Continuous-Time Framework

Setting up the model equations for equities and bonds requires linearisation at least up to the second order. Andreasen (2012) even propose a third order to capture the time-varying effects of the term structure. But standard linearisation would yield risk-neutral market participants, leading to similar prices for all assets. To overcome this dilemma, we follow Paoli, Scott and Weeken (2010b) and Wu (2006) by assuming $\log(SDF_{t+1} \frac{P_t}{P_{t+1}}) = \alpha_0 + \alpha_1 s_t + \alpha_2 \epsilon_{t+1}$, where s_t are the state variables.

However, even this degree of linearisation does not result in realistic modelling of the underlying financial instruments. In Hayo and Niehof (2013a), we propose solving the nonlinear DSGE model by switching to continuous time. We transform the difference equations discussed so far, such as the consumption equation, into a system of continuous-time equations. This transformation permits a more sophisticated inclusion of financial instruments without loss of information due to approximation. Moreover, we can model asset prices as jump-diffusion processes, which reflect market volatility much more realistically than do methods used in similar research. The specification of the financial sector reflects our assumption of simultaneously interacting stock and bond markets. Following Heston (1993), we model the stock market as a stochastic volatility model. This is an extension of Black and Scholes (1973a) and takes into account a non-lognormal distribution of asset returns, leverage effect, and mean-reverting volatility, while remaining analytically tractable. To reflect highly interacting markets, we include the foreign stock mar-

kets, bond prices, exchange rates, output, and interest rates in the drift term. For example, including the output gap in the stock market is in line with Cooper and Priestley (2009) and Vivian and Wohar (2013); a general approach to incorporating macroeconomic factors in stock returns is developed by Pesaran and Timmermann (1995).

In line with Bayer, Ellickson and Ellickson (2010), house prices are modelled as stochastic differential equations taking into account local risk, national risk, and idiosyncratic risk. This allows modelling house prices in an asset pricing environment. As before, we account for macroeconomic variables in the drift term. Consistent with the empirical findings of Adams and Füss (2010), Agnello and Schuknecht (2011), Capozza, Hendershott, Mack and Mayer (2002) and Hirata, Kose, Otrok and Terrones (2012), we include the real interest rate, the output gap, and the derived asset from the stock market in the drift term to account for interconnectedness. To analyse call and put prices, we apply the extended Black-Scholes formula as in Kou (2002).

$$dS = (S_t((r - \lambda\mu) + \rho_b b_t + \rho_b^* b_t^* + \rho_s^* S_t^* + \rho_i i_t + \rho_y y_t + \rho_e e_t + \rho_p i\pi_t))dt + \sqrt{V_t}dW_S(t) + \sum_{i=1}^{dN_t} J(Q_i) \quad (V.41)$$

$$dV_t = \kappa(\theta - V_t)dt + \sigma\sqrt{V_t}dW_V(t)$$

$$db_t = (\gamma_b b_t + \gamma_S S_t + \gamma_s^* S_t^* + \gamma_b^* h_t^* + \gamma_y y_t - \gamma_i(i_t - \pi_t))dt + \sigma_1 dW_b^1(t) + \sigma_2 dW_b^2(t) + \sigma_3 dW_b^3(t) \quad (V.42)$$

where $J(Q)$ is the Poisson jump-amplitude, Q is an underlying Poisson amplitude mark process ($Q = \ln(J(Q)+1)$), and $N(t)$ is the standard Poisson jump counting process with jump density λ and $E(dN(t)) = \lambda dt = Var(dN(t))$. dW_S and dW_V denote Brownian motions. β is the long-term mean level.

Furthermore, the above model can be written as

$$dK_t = (I_t - \delta K_t)dt + \left(1 + V\left(\frac{dI_t}{I_t dt}\right)\right)dI_t \quad (V.43)$$

$$dY_t = dC_t + dI_t + dFM_t + dG_t + a(dZ_t)K_t dt \quad (V.44)$$

Using calculus, each difference equation can be transformed in a similar way. Further details about the derivation of the model can be found in Hayo and Niehof (2013b).

We analyse the model's stability with Lyapunov techniques (Khasminskii 2012). We apply the follow-

ing Lyapunov function

$$V(x) = \|x\|_2^2 = \left(\sqrt{\sum |x_i|^2} \right)^2 \quad (\text{V.45})$$

where $\|\cdot\|_2$ denotes the Euclidean norm. Since the zero solution is only locally stable, there is no global stable rest point only parameter-dependent partial solutions. However, all sets of applied parameters provide stable zero-solutions in the Lyapunov sense.

V.4. Model Calibration

We calibrate the parameters of our system of equations using values from the literature. We use parameters similar to those employed in theoretical and empirical analyses by Fernández-Villaverde (2010), Justiniano, Primiceri and Tambalotti (2010) and Smets and Wouters (2007). For the monetary and fiscal policy parameters we use parameters similar to those of Adolfson, Laseen, Linde and Svensson (2011) and Lindé (2005). Regarding the financial market, we use previously estimated parameters from Hayo and Niehof (2013a, 2014). Table V.1 in the Appendix lists the various parameters and their corresponding values.

The calibration of the household and firm side is standard. Elasticities of substitution regarding investments and consumption ($\eta_d^c, \eta_d^i, \eta_f^c, \eta_f^i$) vary between 1.30 and 1.50, whereas the general elasticity of substitution between domestic and foreign consumption is 2.00, reflecting a bias toward domestic products (Fernández-Villaverde 2010). The share of imports in consumption is 0.75. The household's utility function is similarly to the one employed by Smets and Wouters (2007). The elasticity for substitution of consumption σ is 1.20, the elasticity of substitution for labour σ_l is 1.25. On the supply side, we assume standard Calvo-pricing parameters as in Smets and Wouters (ibid.). The Calvo parameters for prices θ and wages θ_h are 0.75 and 0.66, respectively.

We use monetary and fiscal policy parameters similar to those of Adolfson, Laseen, Linde and Svensson (2011) and Lindé (2005). The inflation parameter ψ_π is 1.20, reflecting our assumption that central bank's chief goal is inflation stability. Government expenditures mainly depend on the output gap ($\varphi_y = 0.80$). Parameters reflecting our assumption of international interaction are taken from empirical results in Hayo and Niehof (2014). For example, the weight of financial markets in the monetary policy reaction function is estimated to be 0.30. For the financial market parameters in the bond and stock market equations, we rely on Hayo and Niehof (ibid.). For example, the stock markets is strongly affected by previous realisations (0.80) and weakly affected by foreign stock markets (0.10). Further details are given in the cited literature.

To derive the dynamic adjustment, we take the mean of 1,000,000 simulations with 0.01 time steps. We use a normalised Euler-Maruyama scheme to simulate the trajectories of the stochastic differential equations. We normalise our time frame to one, interpreting it as five years in the economy.

V.5. Simulation Results

We differentiate between the 16 cases: open economy vs. monetary union, standard vs. modified Taylor rule, spending-oriented vs. austere fiscal policy, and neutral vs. debt-averse market participants. We compare these cases based on impulse responses (see Figures V.1 to V.3) and their respective minima and maxima (see Tables V.2 and V.3). Given the similarity of the models, it is not surprising that impulse response functions more or less coincide. Therefore, we show only selected cases in the form of detailed graphs. As the transmission mechanisms are similar, we believe that the combination of descriptive statistics and graphical means is the most economical way to convey the key results.

Our benchmark case is a two country open-economy setting, with a modified Taylor rule, spending-oriented fiscal policy, and debt-neutral financial market participants. The impulse responses in Figure V.1 showcase the transmission of a stock market crash in the domestic country A (black lines). In the simulation, before the shock occurs, stock markets in both country A and the foreign country B (dashed lines) are on an upward trend. Although A's stock market tanks after the shock, B's stock market continues to rise in the same period. This is due to modelling the stock market equation as an autoregressive process and the assumption of there being a relatively small correlation between these financial markets. However, one period later, B's stock market goes down rapidly as well. After a short period of recovery, A's stock market deteriorates as a consequence of the declining macroeconomic conditions and this development is mirrored by B's stock market. After the recession is over, both stock markets move back to the baseline.

On the real side of the economy, the stock market crash leads to a liquidity shortage for A's firms. As the stock market reflects firms' net worth, the crash caused country A's firms to lose competitiveness. Therefore, output in A starts decreasing only three periods after the crash. Consumption and investment show a very similar development.

Under the modified Taylor rule, monetary policy in A reacts to the financial market shock as well as the developing recession by substantially lowering the interest rate. As investment in B becomes more attractive, capital outflows from A cause a depreciation of its currency. This improves competitiveness in B and helps it to avoid an output contraction similar to that experienced by. Otherwise, the economic adjustment in both countries is very similar.

To stabilise the economy, a fiscal policy of increasing government expenditures is implemented. As

taxes decrease due to the recession, there will be a fiscal budget deficit. In spite of declining output, the combined influence of monetary and fiscal stimulus leads to inflation. The results regarding the financial markets spillover suggest that due to the fiscal deficit, as well as the interdependence of financial markets, domestic and foreign bond markets are affected by the crisis. The decrease in government bond prices, which corresponds to an increase in government bond yields, creates higher borrowing conditions for both countries.

We now analyse differences between the benchmark case and what happens if we vary important model assumptions. First, we compare our extended model with the model in Hayo and Niehof (2013a). Simulations with the standard Taylor rule show (see Tables V.2 and V.3) that the modified monetary policy rule outperforms the standard Taylor rule after a stock market crisis in terms of reducing the size of the recession. However, if the standard Taylor rule is applied, monetary policy is less expansionary, the recession causes deflation, and the exchange rate remains almost unchanged.

Second, we compare the spending-oriented fiscal policy with an austere policy (see Figure V.2 and Tables V.2 and V.3). In the latter case, the increase in government expenditures is mainly financed by a tax increase, but due to the assumed smooth fiscal policy adjustment, some bonds still have to be issued. Thus, during A's recession, taxes do not go down but start increasing due to the government's attempt to limit the fiscal deficit. As country B's recession is less intense, taxes in that country do not need to be raised as aggressively as they are in A. The consequence of an austere fiscal policy is a deepening of the recession, which is in line with the typical result of Keynesian stabilisation policy. However, in addition, our model shows that for stabilising the inflation rate, the austere policy is superior in both countries, a result not commonly derived in models characterised by Ricardian equivalence.

Third, we now assume that households are risk averse with respect to debt (see Tables V.2 and V.3) and, therefore, react negatively to the number of issued government bonds issued. Thus, although the spending-oriented fiscal policy works as before, it does not result in the desired outcome. This is because, following the increase in government bonds, households substantially reduce their consumption expenditure. This additional drop in consumption more than overcompensates the positive impulse coming from fiscal policy. Thus, if households react negatively to the resulting fiscal deficit, the outcome of austere policy in terms of stabilising the output gap during the recession dominates the spending-oriented policy. This result is similar to that derived from models exhibiting Ricardian equivalence, but, as outlined above, the adjustment mechanism here is different.

Fourth, we look at the case of a monetary union, again focussing on a spending-based fiscal policy and a modified Taylor rule as well as risk-neutral households. The results of the simulations are shown in Figures V.3 and Table V.3. Note that we shut down the exchange rate channel and that the interest rate

is roughly the average of A's and B's interest rates in the open-economy case. The consideration of B in the Taylor rule implies that after the stock market crash in A, and the ensuing recession, the monetary policy reaction is not as strong as in the two-country case. At the same time, B benefits from the shared monetary policy. Due to cheap borrowing conditions and fewer recessionary pressures, investments in B increase in spite of the financial crisis. The consequence of this asymmetric development is not only a much lighter recession in B, but also a difference in terms of domestic inflation. Therefore, in a monetary union, a stock market crisis creates notable spillover effects from national financial markets to other countries. Comparing these results with the case of a monetary union with an austerity-oriented fiscal policy shows that the austere policy is less successful in terms of output stabilisation. However, as in the two-country example, introducing risk-averse households overturns this finding, as output in both countries as well as inflation in B fluctuate less.

V.6. Conclusion

In this paper, we study the interaction of monetary and fiscal policy after a financial market crisis in a two-country, open-economy setting as well as in a monetary union setting. Technically, we extend the well-known, open-economy New Keynesian model of Clarida, Gali and Gertler (1999), Lindé, Nessén and Söderström (2009) and Smets and Wouters (2002, 2007) and Lubik and Schorfheide (2007) in two important ways. First, we include a well-developed financial sector and, second, we apply stochastic differential equations and conduct the analysis in a continuous-time framework. The continuous-time approach allows us to employ classic research from the field of finance and model the financial sector by including the markets for foreign exchange, stocks, and bonds. We therefore combine macroeconomic research with advanced methods for capturing financial market processes developed in the finance literature (Merton (1973) and Black and Scholes (1973a)). To guarantee stability we employ Lyapunov techniques (Khasminskii 2012). Thus, in our analysis, we combine DSGE macroeconomic analysis, classic finance research, and standard mathematical procedures.

Our main research question concerns the interaction of different types of fiscal and monetary policy after a financial market crash and how this interaction affects other important macroeconomic variables, particularly output and inflation. We undertake this analysis by looking at various combinations of stabilisation policies and economic environment, that is, independent but globalised economies versus a monetary union. Monetary policy either follows a standard open-economy Taylor rule or a modified rule that includes financial market variables in the central bank reaction function. We also distinguish between a passive or 'austere' fiscal policy, which is primarily concerned with balancing the intertemporal budget constraint, and a spending-based fiscal policy, that is, one that includes bond-financed, expansionary

government expenditure.

After a financial market crash in one country, its economy heads toward a recession. This forces policymakers to lower interest rates and engage in higher government spending. We find evidence that a co-ordinated adoption of fiscal and monetary policy is very effective in lessening the effects of a financial crisis in terms of output. Stabilisation is particularly powerful if the central bank directly reacts to the financial crisis by including a financial market indicator in its Taylor rule. However, such action comes at the cost of increasing the inflation rate in the country where the financial crisis occurred. This positive impact of a debt-financed fiscal expenditure policy is conditional on the assumption that households do not care about the number of bonds issued by the government. If we assume that households are averse to outstanding government debt, the situation changes dramatically. Now we find that a combination of expansionary monetary policy and austere fiscal policy is more appropriate for stabilising both domestic and foreign economies in terms of both output and inflation.

Extending our setup to the case of a monetary union adds another interesting asymmetry and shows significant spillover from a financial crisis in one country to other members of the monetary union. In this case, we find that stabilisation of output in the country where the financial shock originates is no longer as easy as now monetary policy takes into account the other country, the output of which is much less affected, and a depreciation of the domestic currency is no longer possible. Moreover, in terms of inflation, there is now a clear asymmetry, with deflation in the country where the crisis originated and a higher inflation rate in the other country.

Our study has some interesting policy implications. First, by directly reacting to financial market shocks, a central bank can mitigate the resulting crisis in the real economy. This would support arguments for extending the Taylor rule to encompass financial market indicators. Second, co-ordinating monetary and debt-financed expenditure policy to combat a recession following a financial crisis is a powerful way of stabilising the economy. Thus, we find support for the Keynesian approach to stabilisation. Third, this result, however, is highly dependent on the assumption that households do not worry about the number of outstanding government bonds in the economy. As the recent debt crisis in Europe suggested, this is not necessarily the case. Fourth, the alternative would be to constrain fiscal policy to take into account the government budget constraint, often termed 'fiscal austerity'. This type of policy has been severely criticised based on the argument that it would be detrimental to economic recovery. Our results show that, in general, this criticism is not valid. If households are debt averse, it may be that an austere fiscal policy is superior to a spending-oriented fiscal policy in terms of output and inflation stabilisation. Finally, applying our model to the case of a monetary union shows that policymakers should be even more wary with respect to financial crisis spillovers than in standard open economies. Not only are financial

market shocks in one country easily transmitted to other members of the monetary union, monetary policy stabilisation will be much less effective for the country where the crisis started. Moreover, the central bank will find itself in the difficult position that there are diverging price developments within the currency area. In the country where the crisis erupted, a deflationary development is likely, whereas in the other countries, inflation is likely to be observed. This may put even more pressure on the currency area's monetary policy committee and may exacerbate a possible tendency of national representatives to vote in their own country's best interest when it comes to interest rate changes (Hayo and Méon 2013).

V.7. Figures and Tables

Figure V.1.. Spending-oriented Fiscal Policy, Modified Taylor Rule

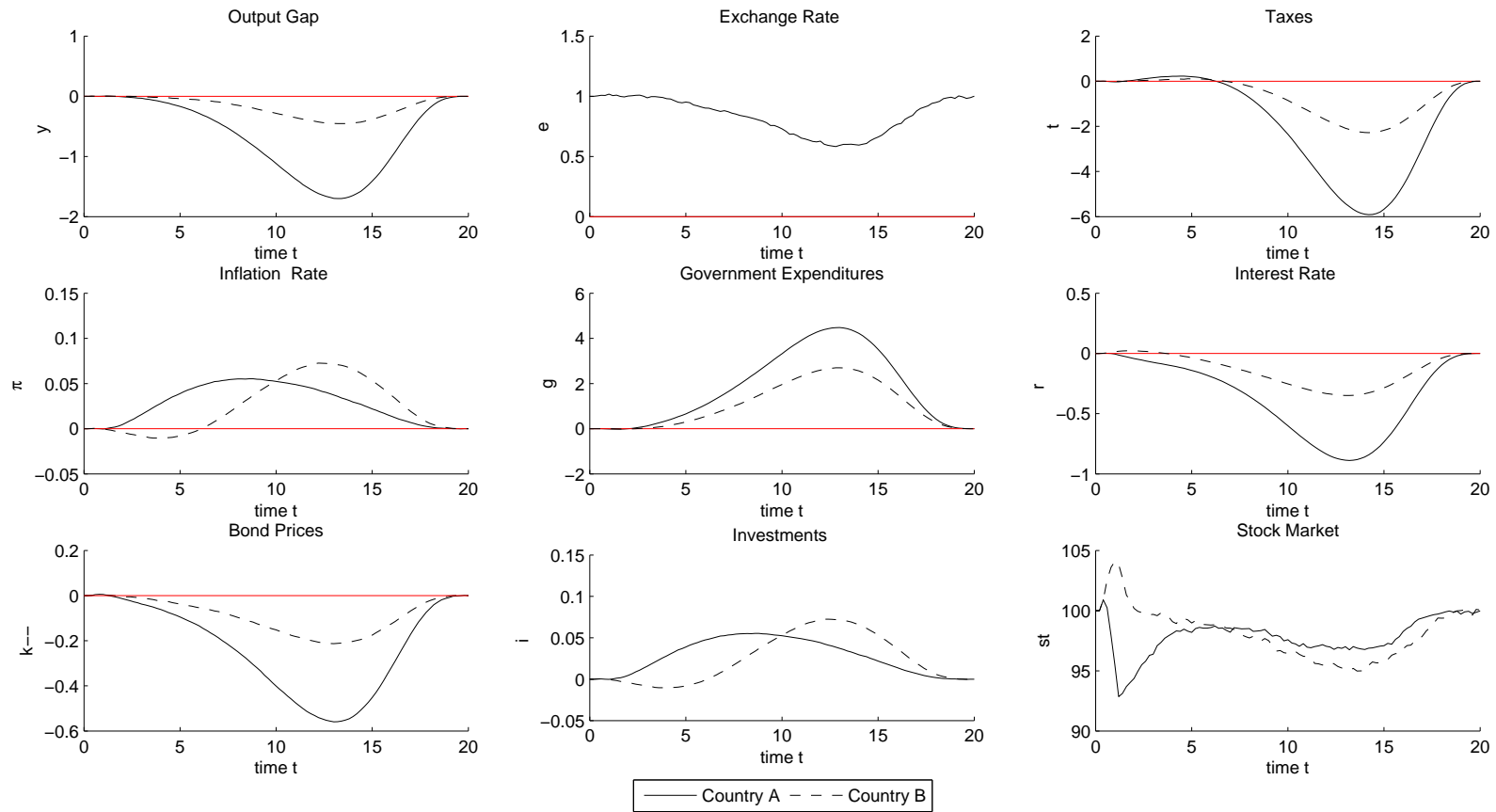


Figure V.2.. Austere Fiscal Policy, Modified Taylor Rule

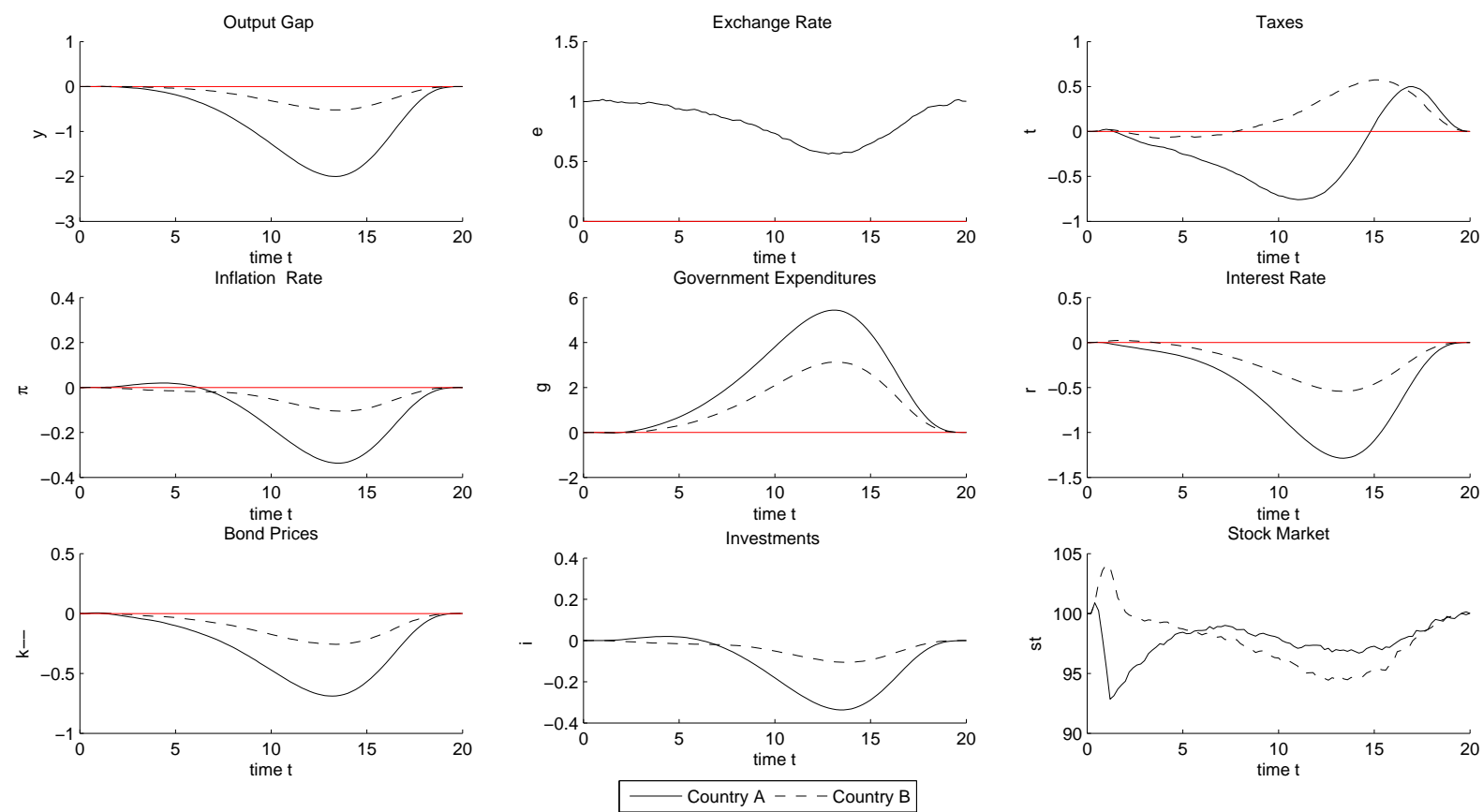


Figure V.3.. Monetary Union, Spending-oriented Fiscal Policy, Modified Taylor Rule

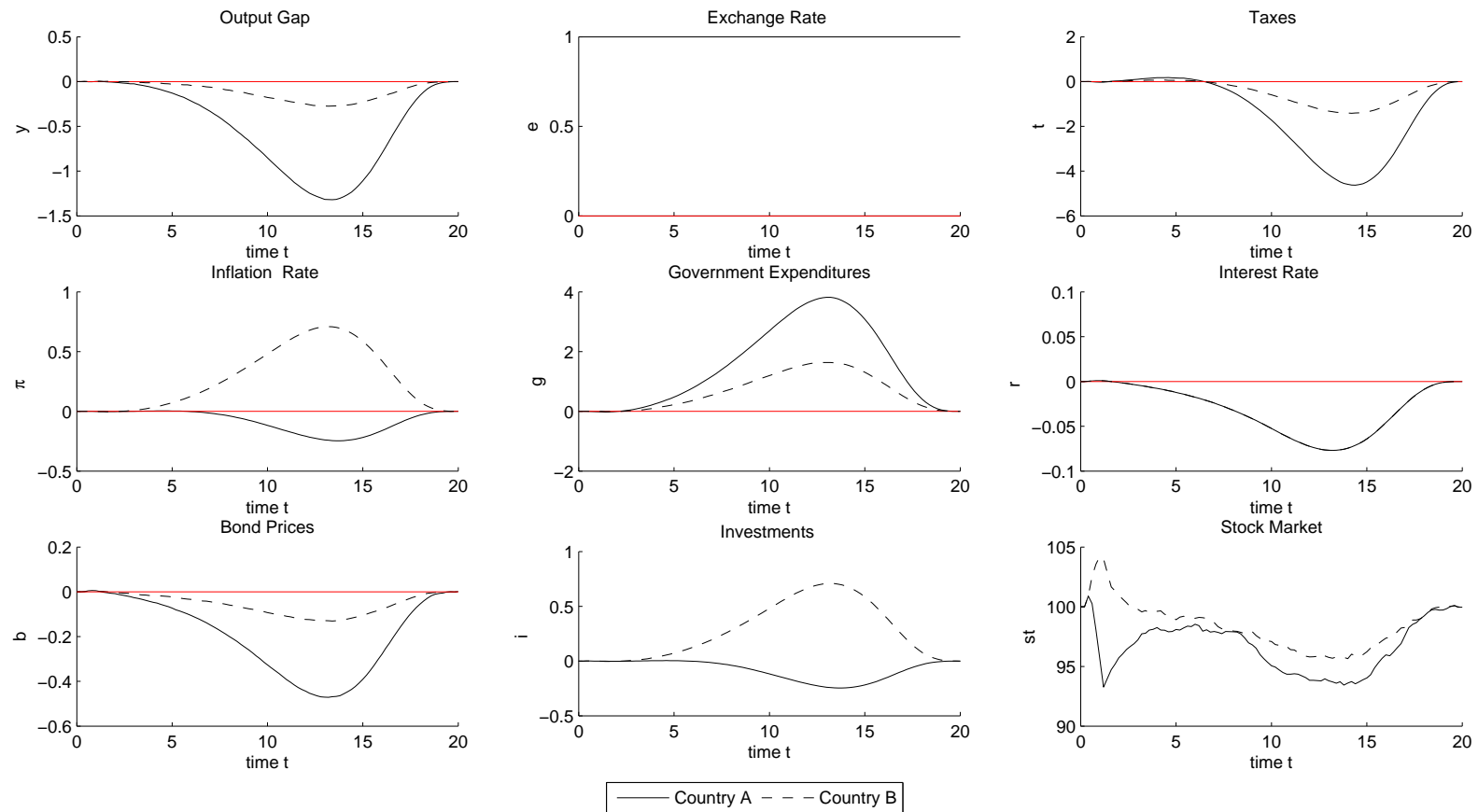


Table V.1.. Parameters

variable	parameter	variable	parameter	variable	parameter	variable	parameter
η_d^c	1.50	ω_x	0.75	ρ_{E*}	0.20	ρ_{r*}	0.10
η_f^c	1.30	ω_{x2}	0.65	S_g	0.20	ρ_y	0.80
η_d^i	1.50	τ	0.20	S_y	0.80	ρ_{fx}	0.50
η_f^i	1.30	θ	0.75	S_b	0.10	ρ_{pi}	0.25
η^c	2.00	ι	0.60	S_{tt}	0.10	γ_h	0.80
ω_f	0.75	π	1.02	S_{yt}	0.95	γ_s	0.30
ω_{f2}	0.65	ϵ	0.55	S_{bt}	0.10	γ_{h*}	0.90
β	0.99	α	0.25	ρ_h	0.20	γ_{s*}	0.90
σ	1.20	ρ_R	0.75	ρ_s	0.80	γ_r	0.90
σ_l	1.25	ψ_{pi}	1.20	ρ_{h*}	0.10	γ_y	0.50
h	0.97	ψ_S	0.30	ρ_{s*}	0.10		
δ	0.30	ψ_E	0.10	ρ_r	0.95		

Table V.2.. Extreme Values - Open-Economy Simulations

open-economy		y	i	π	c	bo	l	r	st	e	g	t		
Classic Taylorrule	risk-neutral	spending	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.02	6.53	0.24
			Min_B	0.00	0.01	0.00	0.00	0.00	0.03	0.00	104.20	0.00	3.79	0.10
			Max_A	-2.08	-0.04	-0.28	-1.87	-0.84	-0.06	-0.04	91.27	0.95	-0.02	-6.86
			Max_B	-0.57	-0.03	-0.08	-0.53	-0.32	-0.01	-0.01	90.84	0.00	-0.01	-2.74
		austere	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.02	6.98	0.81
			Min_B	0.00	0.01	0.00	0.00	0.00	0.03	0.00	104.20	0.00	4.06	0.79
			Max_A	-2.19	-0.05	-0.30	-1.98	-0.89	-0.07	-0.05	90.49	0.92	-0.02	-0.87
			Max_B	-0.57	-0.02	-0.08	-0.54	-0.34	-0.01	-0.01	89.87	0.00	-0.01	-0.07
	risk-averse	spending	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.02	7.92	0.24
			Min_B	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	0.00	4.59	0.09
			Max_A	-2.49	-0.06	-0.34	-2.23	-1.04	-0.07	-0.05	89.28	0.91	-0.02	-7.90
			Max_B	-0.64	-0.02	-0.09	-0.59	-0.40	-0.01	-0.01	88.84	0.00	-0.01	-3.10
		austere	Min_A	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	1.04	7.71	0.92
			Min_B	0.00	0.01	0.00	0.00	0.00	0.03	0.00	104.20	0.00	4.45	0.86
			Max_A	-2.36	-0.04	-0.32	-2.13	-1.00	-0.06	-0.05	90.18	0.91	-0.02	-0.96
			Max_B	-0.61	-0.03	-0.09	-0.57	-0.39	-0.02	-0.01	88.98	0.00	-0.01	-0.07
Extended Taylorrule	risk-neutral	spending	Min_A	0.00	0.00	0.16	0.01	0.01	0.01	0.00	100.90	1.02	4.48	0.22
			Min_B	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	0.00	2.60	0.09
			Max_A	-1.70	-0.43	0.00	-1.50	-0.56	-0.04	-0.11	93.26	0.36	-0.02	-5.80
			Max_B	-0.36	-0.08	0.00	-0.32	-0.20	0.00	-0.06	93.53	0.00	-0.01	-2.11
		austere	Min_A	0.00	0.00	0.18	0.01	0.01	0.01	0.00	100.90	1.03	4.92	0.00
			Min_B	0.00	0.00	0.22	0.00	0.00	0.04	0.00	104.20	0.00	2.85	0.01
			Max_A	-1.81	-0.45	0.00	-1.61	-0.61	-0.04	-0.12	92.57	0.33	-0.02	-2.30
			Max_B	-0.37	-0.09	0.00	-0.33	-0.22	0.00	-0.06	92.93	0.00	-0.01	-0.37
	risk-averse	spending	Min_A	0.00	0.00	0.17	0.01	0.01	0.01	0.00	100.90	1.03	5.03	0.21
			Min_B	0.00	0.00	0.22	0.00	0.00	0.04	0.00	104.20	0.00	2.87	0.09
			Max_A	-1.83	-0.43	0.00	-1.61	-0.64	-0.04	-0.12	93.26	0.35	-0.02	-6.04
			Max_B	-0.38	-0.08	0.00	-0.33	-0.23	0.00	-0.06	92.94	0.00	-0.01	-2.17
		austere	Min_A	0.00	0.00	0.16	0.01	0.01	0.01	0.00	100.90	1.03	4.79	0.46
			Min_B	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	0.00	2.77	0.58
			Max_A	-1.75	-0.44	0.00	-1.54	-0.61	-0.05	-0.12	93.26	0.34	-0.02	-0.68
			Max_B	-0.33	-0.07	0.00	-0.29	-0.22	0.00	-0.06	93.06	0.00	-0.01	-0.06

Table V.3.. Extreme Values - Monetary Union Model

monetary-union		y	i	pi	c	bo	l	r	st	e	g	t		
Classic Taylorrule	risk-neutral	spending	<i>Min_A</i>	0.00	0.01	0.00	0.01	0.01	0.00	100.90	-	6.24	0.21	
			<i>Min_B</i>	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.47	0.09
			<i>Max_A</i>	-1.98	-0.03	-0.34	-1.79	-0.80	-0.06	-0.03	91.00	-	-0.02	-6.51
			<i>Max_B</i>	-0.53	-0.03	-0.01	-0.48	-0.30	-0.01	-0.03	91.76	-	-0.01	-2.50
		austere	<i>Min_A</i>	0.00	0.01	0.00	0.01	0.01	0.01	0.00	100.90	-	6.95	0.81
			<i>Min_B</i>	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.88	0.75
			<i>Max_A</i>	-2.16	-0.03	-0.37	-1.95	-0.89	-0.07	-0.03	89.73	-	-0.02	-0.84
			<i>Max_B</i>	-0.56	-0.03	-0.01	-0.52	-0.33	-0.01	-0.03	90.78	-	-0.01	-0.07
	risk-averse	spending	<i>Min_A</i>	0.00	0.01	0.00	0.01	0.01	0.01	0.00	100.90	-	6.95	0.84
			<i>Min_B</i>	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.80	0.73
			<i>Max_A</i>	-2.13	-0.03	-0.36	-1.92	-0.90	-0.07	-0.03	89.83	-	-0.02	-0.86
			<i>Max_B</i>	-0.54	-0.03	-0.01	-0.50	-0.33	-0.01	-0.03	90.67	-	-0.01	-0.06
		austere	<i>Min_A</i>	0.00	0.01	0.00	0.01	0.01	0.01	0.00	100.90	-	6.43	0.20
			<i>Min_B</i>	0.00	0.02	0.00	0.00	0.00	0.03	0.00	104.20	-	3.58	0.09
			<i>Max_A</i>	-2.00	-0.03	-0.33	-1.80	-0.84	-0.06	-0.03	91.49	-	-0.02	-6.34
			<i>Max_B</i>	-0.52	-0.03	-0.01	-0.47	-0.31	-0.01	-0.03	91.30	-	-0.01	-2.46
Extended Taylorrule	risk-neutral	spending	<i>Min_A</i>	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	5.06	0.56
			<i>Min_B</i>	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	-	2.60	0.48
			<i>Max_A</i>	-1.62	-0.13	-0.07	-1.46	-0.63	-0.04	-0.06	92.03	-	-0.02	-0.60
			<i>Max_B</i>	-0.44	-0.11	0.00	-0.38	-0.22	0.00	-0.06	93.49	-	-0.01	-0.07
		austere	<i>Min_A</i>	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	5.20	0.19
			<i>Min_B</i>	0.00	0.00	0.21	0.00	0.00	0.04	0.00	104.20	-	2.79	0.09
			<i>Max_A</i>	-1.68	-0.13	-0.08	-1.51	-0.65	-0.04	-0.07	92.22	-	-0.02	-5.81
			<i>Max_B</i>	-0.46	-0.12	0.00	-0.40	-0.23	0.00	-0.07	93.13	-	-0.01	-2.21
	risk-averse	spending	<i>Min_A</i>	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	6.40	0.74
			<i>Min_B</i>	0.00	0.00	0.25	0.00	0.00	0.04	0.00	104.20	-	3.25	0.61
			<i>Max_A</i>	-1.98	-0.14	-0.09	-1.77	-0.81	-0.04	-0.08	90.40	-	-0.02	-0.75
			<i>Max_B</i>	-0.51	-0.13	0.00	-0.44	-0.28	0.00	-0.08	91.76	-	-0.01	-0.06
		austere	<i>Min_A</i>	0.00	0.00	0.00	0.01	0.01	0.01	0.00	100.90	-	5.97	0.21
			<i>Min_B</i>	0.00	0.00	0.23	0.00	0.00	0.04	0.00	104.20	-	3.10	0.09
			<i>Max_A</i>	-1.89	-0.13	-0.09	-1.69	-0.76	-0.04	-0.07	90.91	-	-0.02	-6.30
			<i>Max_B</i>	-0.50	-0.12	0.00	-0.43	-0.27	0.00	-0.07	91.96	-	-0.01	-2.30

Chapter VI.

Identification Through Heteroscedasticity in a Multicountry and Multimarket Framework

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Identification Through Heteroscedasticity in a Multicountry and Multimarket Framework

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Abstract

This paper employs Rigobon and Sack's approach for identifying monetary policy shocks through heteroscedasticity and extends it to a multimarket and multicountry framework. We analyse the relationship between monetary policy action taken by the European Central Bank (ECB), the Bank of England, the Bank of Japan, the Bank of Canada, and the Federal Reserve and changes in stock and bond markets. First, we find an increase in the variance of stock and money market returns on days when monetary policy committee meetings are held. Second, we discover significant spillovers after monetary policy action, extending even to large foreign central banks. Third, we find that central bank monetary policy action has a significant impact on domestic as well as foreign financial markets, particularly stock markets. Fourth, there is little evidence of reverse causality. Fifth, bond market changes have no high-frequency impact on either short-term interest rates or stock markets.

KEYWORDS: Financial markets, instrumental variable estimation, identification through heteroscedasticity, spillover effects

JEL CLASSIFICATION: C36, E44, E52, G15

VI.1. Introduction

Effective monetary policy requires properly understanding the monetary transmission mechanism. Understanding the underlying processes helps central bankers implement appropriate monetary policy actions, and this is true of transmission of monetary policy shocks to the real economy as well as to financial markets. Here, we focus on the transmission of such shocks to financial markets. As a consequence of globalisation, reduced barriers to international capital flows, and computerised trading, financial markets are increasingly integrated. Thus, when conducting monetary policy, central banks need to consider other monetary authorities. In addition, internationally integrated financial markets react not only to domestic, but also to foreign, monetary policy. Thus, an assessment of monetary policy transmission in today's globalised world requires a multicountry and multimarket approach.

In a seminal paper, Rigobon and Sack (2004) propose identifying monetary policy shocks through an approach based on heteroscedasticity. The authors argue that the channel from monetary policy to financial markets is not one-sided: that is, monetary policy influences financial markets and financial markets simultaneously affect monetary policy. Accordingly, at least two methodological difficulties arise when estimating the reaction of financial markets to monetary policy. First, there is the problem of endogeneity, causing biased estimators. Because of the simultaneity between policy and market reaction, error terms are correlated with financial market indicators and monetary policy indicators. Second, there are factors other than monetary policy that influence financial markets. As a consequence, estimators could be biased due to omitted variables. Rigobon and Sack (*ibid.*) develop an instrument variable estimator to deal with the simultaneity of policy and financial market reactions. However, they prove its validity for only one monetary policy indicator and one financial market indicator. Given the integrated nature of financial markets, theirs is possibly a too-limited test of the approach.

Recent empirical literature contains several approaches for estimating the effects of monetary policy on financial markets, particularly stock markets. There are basically two broad strands of this literature. Thorbecke (1997) applies a vector autoregressive (VAR) model and an event study to analyse the effect of monetary policy on equity returns. He finds evidence that there are monetary policy risk premia in stock returns and that stock markets react significantly to monetary policy shocks. Patelis (1997) applies VAR and multivariate regressions to study short- and long-run effects and finds a negative association between monetary policy shocks and expected returns. Bjornland and Leitemo (2009b) and Bredin, Hyde and O'Reilly (2010) also employ a VAR framework. Bjornland and Leitemo (2009b) discover evidence that the S&P 500 reacts to monetary policy and that the federal funds rate reacts to stock market shocks. Bredin, Hyde and O'Reilly (2010) find spillover effects from US monetary policy shocks to German and British excess bond returns.

Some studies of monetary policy effects employ higher frequency data, typically daily. Kuttner (2001) and Bernanke and Kuttner (2005), utilising an event study approach, find evidence that Federal Reserve monetary policy has an impact on US stock and bond markets. However, due to the endogeneity problem noted above, an event study analysis provides potentially biased estimates. Rigobon (2003) develops a model based on instrumental variables estimation to correct for such a bias. He utilises heteroscedasticity in the data to derive adequate instruments. Rigobon and Sack (2004) apply this identification through heteroscedasticity approach to analyse monetary policy shocks on US major stock indices and bond markets, and find support for the earlier results of Bernanke and Kuttner (2005).

European financial markets have also been studied. Andersson (2010) uses intraday data in an analysis of monetary policy shocks on US and European financial markets. He finds that monetary policy decisions increase stock and bond market volatility in both regions but that the effect is more pronounced in the United States. Bohl, Siklos and Sondermann (2009), Sondermann, Bohl and PierreSiklos (2009), and Kholodilin, Montagnoli, Napolitano and Siliverstovs (2009) apply the identification through heteroscedasticity approach to European markets. Bohl, Siklos and Sondermann (2009) employ a sample of about 40 monetary policy shock dates, most of which occurred before 2003. The authors analyse how major stock indices (German, Spanish, Italian, and French) react to ECB monetary policy shocks. In a follow-up paper, Sondermann, Bohl and PierreSiklos (2009) also cover the Austrian, Belgian, Finnish, Irish, Dutch, and Portuguese stock market indices. Kholodilin, Montagnoli, Napolitano and Siliverstovs (2009) apply the approach to various sectoral indices. All these papers report that ECB monetary policy has significant effects on European financial markets.

However, all these studies focus exclusively on how domestic monetary policy affects domestic financial markets; that is, they neglect the possible spillover effects of foreign central bank monetary policy on domestic equity indices. Put differently, extent analyses are performed in a bivariate setting and, due to omitted variables, the estimators relied on are potentially biased. Noting the potential importance of international spillover effects, Monticini and Vaciago (2007) apply two-country event studies to the United Kingdom, the Euro area, and the United States. They find evidence that US monetary policy spills over onto European stock and bond markets, but not vice versa.¹ Hayo, Kutan and Neuenkirch (2010) and Hayo and Neuenkirch (2012) find evidence of significant reactions by mature and emerging financial markets to US monetary policy action and communication, respectively. Hayo, Kutan and Neuenkirch (2011) apply a GARCH model to daily financial data and discover that Fed monetary policy communication affects the Canadian financial market, but that Canadian monetary policy communication does not affect US financial markets. In their analysis of US and Australian monetary policy, Craine and Martin

¹ British rates, however, react only marginally to FED policy.

(2008) make the first attempt to analyse monetary policy spillover effects in the framework of identification through heteroscedasticity. They model a two-country, two-market framework and find evidence that US monetary policy has an impact on Australian markets but not vice versa. Ehrmann, Fratzscher and Rigobon (2011a) apply the approach to European and US markets and find significant cross-over effects; however, they do not provide a full proof of their extension. This paper makes several contributions to the literature. First, we extend Rigobon and Sack (2004)'s approach to a multinational and multimarket framework, thus solving the endogeneity and omitted variables problems. Only a few assumptions are necessary to implement this model in a GMM framework and no instruments are needed for the estimation. Second, a multinational and multimarket framework is particularly relevant when studying the impact of monetary policy on major financial markets, given that these are highly integrated. Thus, in this application, we simultaneously analyse the effects of monetary policy on various markets (multimarket) and spillover effects from other monetary policies (multinational). Given the high degree of financial market integration, we expect sizeable national spillover effects of monetary policy, particularly from the European Central Bank (ECB) and the Federal Reserve (Fed), to financial markets.

This paper is organised as follows: Section 2 explains Rigobon and Sack (ibid.)'s approach to the multimarket and multicountry case and derives important characteristics of the estimator. Section 3 then applies this approach to stock and bond markets, specifically, five different central banks and 11 financial markets. A description of the data is followed by the results of the GMM estimation approach and their interpretation as well as a robustness check. Section 4 concludes.

VI.2. Methodology

Endogeneity and omitted variables are two major obstacles to analysing the effect of monetary policy on financial markets. For example, a country's short-term interest rate, a widely used indicator of monetary policy stance, could be influenced not only by domestic asset prices but also by asset prices in foreign countries. At the same time, a country's asset prices could be affected by both domestic and foreign short-term interest rates.

Rigobon and Sack (ibid.)'s framework addresses this issue by applying a simultaneous equation framework estimated by instrumental variables. However, their approach does not address the problem of omitted variables, either with respect to spillover effects from foreign monetary policy and other financial markets or with respect to other factors. To overcome this shortcoming, we extend their framework to a multicountry and multimarket setting and allow a set of macroeconomic variables to enter the model.

By including variables that account for business cycle effects, liquidity premia, shocks, and so forth, we avoid the problem of omitted variables. Assume a set of n countries. Each country is expected

to react to shocks originating in another country. Here we focus on international monetary policy and financial market spillovers. Furthermore we assume a set of common parameters for the macroeconomic factors. We consider n countries, each endowed with one monetary policy rate x and a financial market instrument y .

$$x_i^t = \alpha_{i,1}x_1^t + \dots + \alpha_{i,i-1}x_{i-1}^t + \alpha_{i,i+1}x_{i+1}^t + \dots + \alpha_{i,n}x_n^t + \beta_{i,1}y_1^t + \dots + \beta_{i,n}y_n^t + \gamma_{ix}z^t + \epsilon_i^t \quad (\text{VI.1})$$

$$y_i = \alpha_{i,1}x_1^t + \dots + \alpha_{i,n}x_n^t + \beta_{i,1}y_1^t + \dots + \beta_{i,i-1}y_{i-1}^t + \beta_{i,i+1}y_{i+1}^t + \dots + \alpha_{i,n}y_n^t + \gamma_{iy}z^t + \eta_i \quad (\text{VI.2})$$

where x_i^t is a $n \times 1$ vector representing the first difference in the short-term interest rate of country i at time t and y_i^t is a $n \times 1$ vector representing the first difference of the price of an asset or any other financial market of country i at time t , $\alpha_{i,k}$ are the respective parameters for the vector x_i^t , $\beta_{k,i}$ for the vector y_i^t , γ_k is the parameter for the macroeconomic variable z^t (e.g. risk premia or oil price shocks) and ϵ_j is monetary policy shock, whereas η_j is a financial market shock.

Due to the endogeneity problem, OLS estimates yield biased estimators. However, Rigobon and Sack (2004) show that the simultaneous equations can be estimated consistently using the general method of moments (GMM). A convenient feature of their approach is that the instruments are generated within the data. We adopt this approach in our specification. Given the validity of the underlying assumption, the generalised estimator is consistent. Furthermore, this approach requires fewer assumptions about the variances of the monetary shocks ϵ_i than does an event study approach.

The outline of the proof for the estimator is as follows. We assume that the variance of monetary policy shocks (ϵ_i) is higher on days when monetary policy is actually undertaken than on other days. Thus, given the institutional framework of monetary policy decisions, we assume that market participants do not expect monetary policy action on days when there is no committee meeting. We then separate the sample into country-specific subsample. The first subsample includes all dates on which monetary policy takes place, henceforth referred to as 'monetary policy dates'. The other subsample includes all other dates, henceforth referred to as 'other dates'. Variances on monetary policy dates should be significantly higher than those on other dates, whereas variances of financial market shocks (μ_i) or variances of the set of macroeconomic variables (z_i) should be similar in both samples. For each subsample, we develop the corresponding covariance matrices. Except for the case of monetary policy shocks, these matrices should be similar. We then use these covariance matrices to derive our estimator, using the estimated covariance matrix of each subsample.

As explained above, we split the sample into two subsamples, F_i^m up to F_i^o , where F_i^m includes all monetary policy dates in country i and F_i^o includes the remaining non-monetary-policy dates. This

implies:

$$\sigma_{\varepsilon_i}^{F_i^m} > \sigma_{\varepsilon_i}^{F_i^o}, \quad (\text{VI.3})$$

$$\sigma_{\eta_i}^{F_i^m} = \sigma_{\eta_i}^{F_i^o}, \quad (\text{VI.4})$$

$$\sigma_{z_i}^{F_i^m} = \sigma_{z_i}^{F_i^o}, \quad (\text{VI.5})$$

for all countries $i, i = 1 \dots n, t = 1 \dots T$. Furthermore, we assume that all disturbances and variables are uncorrelated. To identify the system of equations above, we use matrix notation:

$$u_t = By_t + \Gamma z_t, \quad (\text{VI.6})$$

$u_t = [\varepsilon_{1t} \dots \varepsilon_{nt} \eta_{1t} \dots \eta_{nt}]'$, B is the $2n \times 2n$ coefficient matrix, $Y_t = [x_{1t} \dots x_{nt} y_{1t} \dots y_{nt}]'$ and $\Gamma = -[\gamma_{1x} \dots \gamma_{nx} \gamma_{1y} \dots \gamma_{ny}]'$.

To compute the reduced form, and thus solve this equation, we need the inverse B^{-1} of B . Showing that such an inverse exists is straightforward, as all the rows of matrix B are independent, and can be summarised as follows:

$$Y_t = B^{-1}(u_t + \Gamma z_t) \quad (\text{VI.7})$$

$$= \frac{1}{\det(B)} \text{adj}_B(\Gamma z_t + u_t) \quad (\text{VI.8})$$

where adj_B is the adjoint of matrix B and the vector $B^{-1}u_t$ can be characterised as a structural shock, including both monetary and financial market shocks. The principal idea of this estimation technique is to utilise the covariance of each subsamples F_i^m and F_i^o to obtain an estimator with the desired properties.

For n countries we include n regimes, meaning that there is a special monetary policy regime for each country. For the sake of simplicity, we do not consider more regimes, although their inclusion would be easily implemented. From the reduced form, we can compute the covariance matrix for the set of countries. For the sake of simplicity, we assume a zero mean.

$$\begin{aligned} \text{Cov}(y_t y_t') &= \text{Cov} \left[\left(\frac{1}{\det(B)} \text{adj}_B(\Gamma z_t + u_t) \right) \left(\frac{1}{\det(B)} \text{adj}_B(\Gamma z_t + u_t) \right)' \right] \\ Y_t &= \frac{1}{\det(B)} E((\text{adj}(B)(\Gamma z_t + u_t)(\text{adj}(B)(\Gamma z_t + u_t))') \end{aligned}$$

For example the first entry in the covariance matrix is

$$E(\tilde{b}_{11}^2 (\gamma_{1x} z_t + u_1)^2 + \dots + E(\tilde{b}_{1n}^2 (\gamma_{ny} z_t + u_n)^2)$$

where \tilde{b}_{ij} is the adjoint element.

Each covariance matrix contains $4n^2 - (n - 1)$ different elements. Given that we have n regimes, we therefore have $n \cdot 4n^2 - n(n - 1)$ different elements in the covariance matrices. The covariance matrix of regime $s \in [0, n]$ and its estimates are called Σ_s and Ω_s , respectively.

As the system is overidentified, the remaining equations can be used for testing overidentifying restrictions. The estimation has a minimum distance interpretation. Each regime can be thought of as an instrument. Rigobon and Sack (2004) prove that in the absence of common shocks, more than two regimes are required to achieve identification.

Estimation is simple. First, we run a VAR model with exogenous variables (VARX) on the log of the yields, which removes serial correlation from our data series. Second, we compute the covariance matrix for each subsample (defined by the different regimes). These covariance matrices can be used for GMM estimation of the contemporaneous coefficients. By definition, no further instrument is needed in this kind of estimation technique. For the sake of simplicity, $s = 0$ is the case without any monetary policy action. We use the covariance matrices to minimise

$$\min_{\alpha_i, \beta_i} (\Sigma_s - \Omega_s) \quad (\text{VI.9})$$

For the identification problem, the set of equations must be linearly independent. By assumption, the volatility of monetary policy regimes is higher than that of the base regime, which assures identification. We use the additional equations of the moment conditions to test for overidentifying restrictions.

VI.3. Data and Empirical Results

In this section, we analyse how monetary policy action by the Bank of England (BoE), the European Central Bank (ECB), the Federal Reserve (Fed), the Central Bank of Canada (BoC), and the Central Bank of Japan (BoJ) influences major stock and bond market indices using daily data from January 1999 to March 2014. To keep the analysis manageable, we focus on the largest economies: the United States, Canada, the United Kingdom, Japan, Germany, France, and Spain. To incorporate the effect of the European sovereign debt crisis, we also consider Greece and Ireland as examples of highly indebted countries.

As our indicator for monetary policy, the pendant to the variable x_i^t in the methodology section, we use one-month money market rates as measured by Euribor, Libor, Canadian Libor, Japanese Libor, and Eurodollars. These indicators are computed as daily differences in basis points. The interbank interest rate primarily reacts to monetary policy action and not very much to other events, which makes it a good

indicator for measuring monetary policy shocks. We follow Kleimeier and Sander (2006) in choosing one-month interbank rates as they are less volatile than overnight interest rates but more sensitive than rates with longer maturities. As stock indices, the pendant to the variable y_i^t in the methodology section, we employ log differences in basis points of daily closing prices for the Canadian TSX, the French CAC 40, the German DAX, the Greek ASE, the Irish ISEQ, the Japanese Nikkei, the UK FTSE, the US S&P, and the Spanish IBEX 35². As bond market indicators in the various countries we use the national sovereign debt bonds with one-year maturity.³

The ECB governing council makes decisions on future monetary policy 12 times per year⁴ and decisions are announced at 1:45 pm on the meeting day. The Monetary Policy Committee (MPC) of the Bank of England also meets 12 times per year, and its decisions are published at 11 am. The Federal Open Market Committee meets eight times per year, announcing its decisions at 2 pm. The Governing Council of the Canadian Central Bank meets four times a year; the announcement is at 10 am the next day. The Policy Board of the Bank of Japan meets 14 times a year and announce its decision at 8 am the next day. We expect markets to incorporate monetary policy decisions after their announcement. Thus, as interbank market rates are already fixed on the decision days, we employ money market quotes from the subsequent day to capture the change due to the monetary policy move. We have 216 monetary policy meeting dates for the euro area, 222 for Japan, 184 for the United Kingdom, 130 for the United States, and 109 for Canada.⁵ To demonstrate that interbank rates react vigorously on monetary policy dates compared to non-monetary policy dates, we take the mean of each interbank rate on monetary policy dates and on non-monetary policy dates. Figure VI.1 shows that on monetary policy dates, interbank rates are higher than on normal dates.⁶ Standard deviations of major stock indices, and particularly those of short-term interest rates, are substantially higher on monetary policy action dates than on other dates. Descriptive statistics for all series VI.1 suggest the general validity of this identification approach. As argued by the present value model (see e.g. Crowder (2006)), monetary policy influences stock markets in two ways. First, today's monetary policy influences the expected future cash flow and, second, it affects the discount rate of financial market participants. Thus, a hike in the monetary policy rate will lead to a decline in stock prices.

Finally, we apply the Hausman test for endogeneity, which supports the hypothesis of an endogeneity problem in the data. In fact, the null hypothesis that OLS estimation is consistent must be rejected for all countries at the 5% significance level. The results obtained by the application of the generalised

² Data source: web pages of the respective central banks.

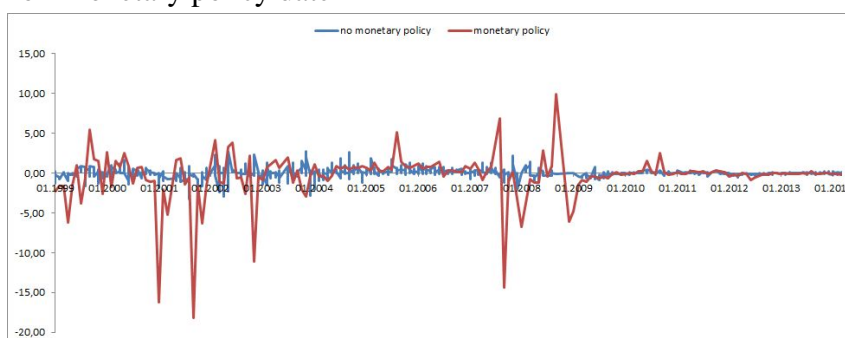
³ Data source: Datastream.

⁴ Until November 2001, the ECB had a different meeting schedule.

⁵ Since some of these dates coincide, we have a total of 704 monetary policy meeting dates.

⁶ Monetary policy is not conducted on the same date world wide. We assigned each monetary policy date to its closes component abroad. Similarly, we pinned monetary policy dates to its five day previous counterpart.

Figure VI.1.. Euribor volatility: comparison of monetary policy action dates and the respective non-monetary policy date



identification through heteroscedasticity approach support most of our expectations. Tables VI.3 to VI.4 present the reaction of stocks, interest rates, and bonds to changes in selected variables.

In Table VI.2, we obtain significant spillover effects from monetary policy by five major central banks to short-term interest rates in other countries. In 60% of the cases, these effects are positive; in 40% of the cases we find negative spillovers. There are large spillovers from Federal Reserve, ECB, and Bank of England policy actions to other monetary policy institutions, whereas the effects on foreign short-term interest rates from Canada and the Bank of Japan are small. We also find that stock market changes influence short-term interest rates, both within and across borders. However, the magnitude of these effects is small, indicating that monetary policymakers do not react much to financial market developments; the signs of the spillovers are negative in almost 50% of the cases.

Table VI.3 provides estimates of how spillovers from monetary policy affect stock markets. Stock markets frequently react to monetary policy actions, again both within and across countries, e.g., a higher policy rate in the euro area causes lower stock returns in Canada. US and European monetary policy have particularly significant effects on major stock markets. However, signs can go in either direction and, in the majority of cases, there is no significant spillover effect; remarkably, not even in the case of the S&P following US monetary policy changes.

Table VI.4 studies the interconnectedness of stock markets across countries. We find strong evidence that globalisation is having an impact, as most of the relationships are statistically significant. In some cases, the effects are quite large, for instance, spillovers from US stock markets to Canadian stock markets. Most of the time, we find a positive transmission of shocks across international stock markets.

Table VI.5 analyses the relationship between monetary policy actions and bond markets. Here, we discover few significant reactions across our sample of countries. In many cases, bond markets do not even react to domestic monetary policy changes, with the notable exception of the United States.

Finally, Table VI.6 suggests that international spillovers are somewhat more pronounced between

stock and bond markets. Here, we find more evidence of international financial market integration than in the case of monetary policy shocks. Still, spillovers from stock to bond markets are less prominent than between stock markets in different countries and the effects are stronger on a national level than on an international level.

Next, we check the robustness of our results (detailed estimation results are available on request). First, we look at how stocks and short-term interest rates react to changes in bonds; however, as we found no significant spillovers, these estimates are omitted here. These results suggest that there is no immediate high-frequency impact of bond market changes on the other variables in our analysis.

Second, we compare the spillovers effects before and after the financial crisis and discover that the size of the parameters differs. Generally, before the financial crisis, monetary policy spillovers and financial market spillovers were of a smaller magnitude than after the financial crisis, for instance, the spillovers from European monetary policy to US monetary policy. One exception to this finding is the monetary policy spillover effect from the US to Canada, which slightly decreases after the crisis, possibly due to an increasing independence of Canadian monetary policy from US monetary policy within the last decade (Michael Bordo and Schembri 2007). Third, the terrorist attack on 11 September 2001 may have an important impact on our results. We generally control for this event by including a dummy variable in our estimations. Excluding this impulse dummy, however, does not notably change our results.

Fourth, we employ a different set of non-monetary policy dates. Instead of the day preceding council meetings, we utilise observations from one week before. Again, this variation does not significantly change our results.

Fifth, we include dummies in the analysis to control for (i) specific effects of the financial crisis and (ii) the direction of monetary policy, i.e., we test for asymmetries in the strength of stock market reactions depending on the direction of interest rate changes. Again, our previous results prove to be robust.

Sixth, we employ three-month money market rates rather than one-month rates. This variation has only negligible influence on our results. Finally, we employ alternative national stock market indices and, again, our results hold up.

VI.4. Conclusions

In this paper, we apply Rigobon and Sack (2004) identification through heteroscedasticity approach to a multicountry and multimarket model. In an empirical application, we examine the influence of monetary policy, measured by short-term interest rates, on domestic and foreign stock and bond markets. Our analysis shows that the major monetary policy institutions significantly influence each other. The Fed generates the greatest spillovers to other central banks, whereas the Bank of Canada generates the smal-

lest. Our analysis shows that stock and bond market developments have a limited influence on monetary policy rates. In contrast, stock markets are strongly influenced by monetary policy action, not only by the domestic central bank but also by foreign central banks. Bond markets react much less strongly to short-term interest rate changes, especially from foreign central banks. Moreover, a number of estimated spillovers have negative signs, which means that the direction of international interconnectedness between monetary policy and financial markets does not necessarily move in one direction. Finally, bond market changes have no high-frequency impact on either short-term interest rates or stock markets.

When analysing the time before and after the onset of the financial crisis, we find that our estimated coefficients are higher after 2007 than before. This suggests that either the financial crisis led to stronger spillovers or that the process of financial market globalisation was not slowed by the financial crisis. However, given the breakdown of money markets in many countries and the reduction in international activity by many banks, the former alternative seems more likely.

Comparing our estimates based on an extended version of the original Rigobon and Sack (2004) approach with the previous findings of Bohl, Siklos and Sondermann (2009), we find that the qualitative findings for stock market effects after domestic monetary policy are broadly similar, but that our estimated coefficients are smaller. There are two possible reasons for this difference. First, it might be due to the inclusion of all council meeting dates in our analysis, instead of focusing on preselected shock dates as done by Bohl, Siklos and Sondermann (*ibid.*). In our view, it is likely that days characterised by particularly large deviations from expectations cause stronger financial market reaction. Second, our smaller coefficients could be due to our use of a multicountry and multimarket approach, which should be less prone to estimation biases than the approach taken by Bohl, Siklos and Sondermann (*ibid.*).

In a world of integrated financial markets, the results of our study have two important implications for monetary policy. First, in line with Bohl, Siklos and Sondermann (*ibid.*), we find evidence that the efficient market hypothesis does not hold in the short run. Monetary policy has a significant impact on financial markets. Second, we detect spillover effects from major monetary policy institutions to global markets. Thus, the central banks, although legally obliged to focus on their domestic area, need to be aware of the spillover effects their monetary policy actions have on other financial markets.

This work is a starting point for fruitful paths of future research. Recent research shows that modern monetary policy does not rely only on action, i.e., interest rate changes, but also on communication of the monetary stance and economic outlook (Ehrmann and Fratzscher (2007); Hayo, Kutan and Neuenkirch (2011)). Our analysis of central bank meeting dates could be extended to include days of formal or informal central bank communication and a study made of the effect these events have on monetary policy issues.

VI.5. Tables

Table VI.1.. Descriptive Statistics of the Monetary Policy Rate

	Standard Deviation						Correlation Coefficient					
	Total		Before Crisis		After Crisis		Total		Before Crisis		After Crisis	
	F_0	F_i	F_i	F_0	F_i	F_0	F_i	F_0	F_i	F_0	F_i	F_0
Canada	0.33	0.55	0.33	0.44	0.33	0.68	-0.05	0.08	-0.05	0.04	-0.06	0.15
France	0.47	0.68	0.46	0.57	0.48	0.80	0.02	-0.03	0.01	-0.05	0.03	0.04
Eurozone	0.43	0.64	0.39	0.46	0.46	0.83	0.02	-0.01	0.03	-0.01	0.01	0.00
Germany	0.48	0.70	0.49	0.66	0.47	0.75	0.00	0.03	0.02	0.02	-0.02	0.04
Greece	0.57	0.79	0.49	0.65	0.65	0.94	0.03	0.01	0.05	0.00	0.00	-0.07
Ireland	0.41	0.64	0.37	0.43	0.46	0.85	0.04	-0.03	0.08	-0.03	0.00	-0.07
Japan	0.49	0.69	0.47	0.58	0.51	0.83	0.03	0.00	0.04	-0.01	0.02	0.00
Spain	0.45	0.65	0.42	0.49	0.50	0.82	0.03	-0.03	0.03	-0.05	0.04	0.00
UK	0.35	0.53	0.34	0.42	0.37	0.64						
US	0.37	0.61	0.37	0.49	0.37	0.75						
Canada	1.05	2.87	1.16	2.62	0.91	3.18						
Euro	0.74	2.03	0.79	2.22	0.67	1.72						
Japan	0.39	0.72	0.40	0.84	0.36	0.50						
UK	1.87	4.28	2.16	4.06	1.44	4.56						
USA	0.83	4.00	0.93	4.07	0.69	3.88						

F_0 denotes non-monetary policy dates and F_i all monetary policy dates of country i .

Table VI.2.. GMM Results, 1/5

Contemporaneous Effects to Monetary Policy Rate

to		Monetary Policy Rate				
from		Can	Eur	Jap	UK	US
Monetary Policy Rates	Can		0.25* (0.04)	-0.53* (0.01)	-0.11* (0.02)	0.44* (0.13)
	Eur	0.10* (0.02)		1.10* (0.01)	0.23* (0.01)	-0.06* (0.08)
	Jap	-0.03* (0.01)	0.17* (0.01)		-0.03* (0.00)	0.07* (0.03)
	UK	-0.4* (0.05)	2.24* (0.06)	-2.06* (0.2)		0.83* (0.04)
	US	0.62* (0.03)	-0.22* (0.05)	1.76* (0.12)	0.31* (0.01)	
Stocks	Can	0.02* (0.00)	-0.03* (0.01)	0.02 (0.02)	0.01* (0.00)	-0.01 (0.00)
	Eur	0.00 (0.00)	-0.01 (0.00)	-0.02* (0.01)	0.01* (0.00)	-0.01* (0.00)
	Fra	-0.01* (0.00)	0.00 (0.00)	0.03* (0.01)	0.01* (0.00)	0.00 (0.00)
	Gre	0.01 (0.01)	0.05* (0.02)	-0.11* (0.04)	-0.01 (0.01)	0.00 (0.01)
	Ire	-0.04* (0.01)	-0.05* (0.01)	-0.04 (0.03)	0.02* (0.00)	-0.01 (0.01)
	Jap	0.01* (0.01)	-0.04* (0.01)	0.00 (0.03)	0.03* (0.00)	-0.04* (0.01)
	Esp	0.01* (0.00)	0.00 (0.01)	0.01 (0.02)	0.00 (0.00)	0.00 (0.00)
	UK	0.00 (0.00)	0.01* (0.00)	-0.01 (0.01)	-0.01* (0.00)	0.01* (0.00)
	US	0.00 (0.00)	0.01 (0.01)	-0.01 (0.02)	0.00 (0.00)	0.00 (0.00)
	Ger	0.02* (0.00)	0.00 (0.01)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)

Values in parentheses are standard errors.

* 5% significance level

Table VI.3.. GMM results, 2/5

Contemporaneous Effects to Stock Market Indices

to from		Stock Market Indices									
		Can	Fra	Eur	Ger	Gre	Ire	Jap	Esp	UK	US
Monetary Policy Rates	Can	-0.20 (0.16)	0.55 (0.32)	-1.47* (0.31)	-0.24 (0.24)	0.03 (0.07)	-0.14 (0.11)	-0.63* (0.09)	0.11 (0.16)	1.14* (0.3)	-0.12 (0.16)
	Eur	-0.27* (0.17)	0.08 (0.16)	-0.27 (0.13)	-0.02 (0.04)	0.09* (0.06)	-0.28* (0.05)	-0.16* (0.09)	0.01 (0.16)	0.52* (0.08)	0.07 (0.01)
	Jap	0.03 (0.07)	0.23* (0.06)	-0.16* (0.05)	-0.01 (0.01)	-0.03* (0.02)	-0.03 (0.02)	0.00 (0.03)	0.03 (0.06)	-0.07 (0.03)	-0.01 (0.00)
	UK	0.59* (0.26)	-1.17* (0.53)	3.1* (0.51)	0.23 (0.4)	-0.18 (0.11)	1.02* (0.18)	1.24* (0.15)	-0.19 (0.27)	-3.1* (0.49)	0.00 (0.26)
	US	0.63* (0.27)	-1.34* (0.26)	-0.03 (0.2)	1.24* (0.06)	0.07 (0.09)	-0.54* (0.08)	0.15* (0.14)	0.35* (0.25)	0.13 (0.13)	0.10 (0.02)
		Values in parentheses are standard errors.									
		* 5% significance level									

Table VI.4.. GMM results, 3/5
Contemporaneous Effects to Stock Market Indices

	to from	Stock Market Indices									
		Can	Fra	Eur	Ger	Gre	Ire	Jap	Esp	UK	US
Stocks	Can		0.14* (0.05)	0.25* (0.05)	-0.47* (0.04)	0.03* (0.01)	-0.14* (0.02)	0.13* (0.02)	-0.07* (0.03)	0.26* (0.05)	0.88* (0.02)
	Eur	0.06* (0.01)	0.23* (0.02)		0.17* (0.02)	0.00 (0.01)	-0.08* (0.01)	-0.01 (0.01)	0.14* (0.01)	0.64* (0.02)	-0.06* (0.01)
	Fra	0.03* (0.01)		0.22* (0.02)	0.43* (0.02)	-0.01* (0.01)	0.05* (0.01)	-0.01 (0.01)	0.27* (0.01)	0.17* (0.02)	-0.06* (0.01)
	Gre	0.15* (0.06)	-0.31* (0.12)	0.05 (0.11)	0.22* (0.09)		0.43* (0.04)	0.1* (0.03)	0.38* (0.06)	-0.07 (0.11)	-0.29* (0.06)
	Ire	-0.28* (0.03)	0.44* (0.07)	-0.6* (0.07)	-0.16* (0.05)	0.16* (0.02)		0.01 (0.02)	0.13* (0.04)	1.09* (0.06)	0.34* (0.04)
	Jap	0.34* (0.04)	-0.06 (0.09)	-0.14 (0.08)	0.06 (0.06)	0.05* (0.02)	0.01 (0.03)		-0.03 (0.04)	0.36* (0.08)	-0.34* (0.04)
	Esp	-0.07* (0.02)	1.05* (0.04)	0.49* (0.05)	-0.26* (0.04)	0.07* (0.01)	0.06* (0.02)	-0.01 (0.01)		-0.57* (0.05)	0.09* (0.02)
	UK	0.07* (0.01)	0.19* (0.02)	0.69* (0.02)	-0.04* (0.02)	0.00 (0.01)	0.15* (0.01)	0.04* (0.01)	-0.17* (0.01)		-0.04* (0.01)
	US	0.84* (0.02)	-0.25* (0.05)	-0.22* (0.05)	0.59* (0.04)	-0.05* (0.01)	0.17* (0.02)	-0.12* (0.01)	0.09* (0.03)	-0.15* (0.05)	
	Ger	-0.2* (0.02)	0.75* (0.03)	0.29* (0.03)		0.02* (0.01)	-0.03* (0.01)	0.01 (0.01)	-0.12* (0.02)	-0.06* (0.03)	0.26* (0.02)

Values in parentheses are standard errors.

* 5% significance level

Table VI.5.. GMM results, 4/5

Contemporaneous Effects to Bond Markets

to from		Bond Markets									
		Can	Fra	Eur	Ger	Gre	Ire	Jap	Esp	UK	US
Monetary Policy Rates	Can	-0.01 (0.04)	0.04 (0.01)	0.00 (0.04)	-0.01 (0.00)	0.00 (0.00)	-0.01 (0.02)	0.00 (0.01)	0.00 (0.01)	-0.03* (0.01)	-0.02 (0.09)
	Eur	-0.02* (0.02)	0.00 (0.01)	0.01 (0.02)	0.01 (0.00)	0.00 (0.00)	0.01* (0.01)	0.03* (0.00)	-0.01* (0.01)	-0.01 (0.01)	0.01 (0.05)
	Jap	0.01 (0.01)	-0.02 (0.00)	0.00 (0.01)	0.01 (0.00)	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.02)
	UK	0.06 (0.03)	0.08 (0.08)	-0.03 (0.03)	-0.11 (0.08)	0.00 (0.00)	-0.01 (0.01)	-0.15* (0.04)	0.03* (0.01)	0.05* (0.02)	-0.07* (0.02)
	US	0.00 (0.02)	-0.05 (0.05)	0.00 (0.02)	0.04 (0.05)	0.00 (0.00)	0.00 (0.00)	0.07* (0.02)	-0.01 (0.01)	0.00 (0.02)	0.04* (0.01)

Values in parentheses are standard errors.

* 5% significance level

Table VI.6.. GMM results , 5/5
Contemporaneous Effects to Bond Markets

	to from	Bond Markets									
		Can	Fra	Eur	Ger	Gre	Ire	Jap	Esp	UK	US
Stocks	Can	-0.01 (0.00)	-0.02* (0.01)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0* (0.00)	-0.01* (0.00)	0.00 (0.00)	0.01* (0.00)	0.00 (0.00)
	Eur	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01* (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01* (0.00)
	Fra	0* (0.00)	0.01* (0.00)	0.00 (0.00)	-0.01* (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01* (0.00)	0.00 (0.00)	0.00 (0.00)
	Gre	0.00 (0.01)	-0.02 (0.02)	0.00 (0.01)	0.02 (0.02)	0.01* (0.00)	-0.01* (0.00)	-0.01 (0.01)	0.00 (0.00)	0.00 (0.01)	0.00 (0.01)
	Ire	0.00 (0.00)	0.02* (0.01)	0.00 (0.00)	-0.02 (0.01)	0.00 (0.00)	0.00 (0.00)	0.01* (0.01)	0.00 (0.00)	0.00 (0.00)	-0.01* (0.00)
	Jap	-0.01 (0.01)	0.00 (0.01)	-0.01* (0.00)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.08* (0.01)	0.00 (0.00)	-0.01 (0.00)	0.01* (0.00)
	Esp	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-0.01* (0.00)	0.00 (0.00)	0.00 (0.00)
	UK	0.01* (0.00)	0.00 (0.00)	0.00 (0.00)	-0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01* (0.00)	0.00 (0.00)	0.00 (0.00)	0.01* (0.00)
	US	0.01* (0.00)	0.02* (0.01)	0.00 (0.00)	-0.02* (0.01)	0.00 (0.00)	0.01* (0.00)	0.01* (0.00)	0.00 (0.00)	-0.01* (0.00)	0.01* (0.00)
	Ger	-0.01* (0.00)	-0.01* (0.00)	0.00 (0.00)	0.01* (0.00)	0.00 (0.00)	0.01* (0.00)	0.00 (0.00)	0.00 (0.00)	0.01* (0.00)	0.00 (0.00)
Values in parentheses are standard errors.											
* 5% significance level											

Chapter VII.

Spillover Effects in Government Bond Spreads: Evidence from a GVAR Model

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Spillover Effects in Government Bond Spreads: Evidence from a GVAR Model

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Abstract

This paper analyses the main driving factors of sovereign bond spreads in a globalised world. We contribute to the existing VAR literature by applying a Global VAR approach, which covers international linkages and spillovers and also deals with the issue of identification and the large dimensionality. In particular, we account for international spillovers of bond spreads by adding a further driving factor, namely financial markets, and allowing interactions across countries and markets. We find significant spillovers across countries and across markets. Moreover, we reveal that bond spreads are driven by stock markets. Furthermore, highly indebted countries react stronger to foreign shocks than stable economies. European bond markets are primarily driven by European shocks, whereas US shocks have a higher impact on European crisis countries and other non-European OECD countries. Our results demonstrate the importance of awareness of global interdependencies of financial market participants as well as central bankers and fiscal policy makers as bond spread volatility is driven by different factors for each country.

KEYWORDS: GVAR, bond spreads, financial markets, global transmission, shocks

JEL CLASSIFICATION: E44, F3, C5

VII.1. Introduction

In April 2010, 'The Economist' stated that 'the Greek debt crisis was spreading. Europe needed a bolder, broader solution'. At that point, government policy-makers began to (again) take notice of sovereign bond spreads. More than four years later, in August 2014, 'The Economist' revealed that the sovereign debt crisis was still 'taking Europe's pulse'. The drivers of these spreads thus continue to be of huge interest to policy-makers, economists, and analysts. Understanding these influences allows policy-makers to better design policy targeted at diminishing risks and improving refinancing conditions. Research has established liquidity, risk aversion, exchange rate, and a country's credit risk as the main driving factors (Ang and Longstaff 2013; Codogno, Favero and Missale 2003). We contribute to this research by considering financial markets as an additional driving factor. In a globalised world, where financial spillovers are not confined to just financial markets, we argue that bond and stock markets are highly interconnected.

Since the run-up to the European Monetary Union (EMU), bond spreads have tended to decline, although they increased tremendously after the outbreak of the global financial crisis. As diminished exchange rate risk has led to the co-moving small European government bond spreads, national risk factors became evident. After the Lehman Brothers disaster, there was a 'flight to safety' that left riskier countries short of capital. The impact of globalisation has become stronger and, especially in bad times, stock market impacts are substantial. This implies that European countries were considered by a similar risk in stable times but by a different risk in times of crisis. This revealed a huge imbalance within the EMU. The increasing sovereign debt in the Eurozone has induced market participants to expect either an exit from the Euro or even the collapse of the common currency.

Bilateral relationships change over time and capturing this time-varying component is difficult by standard means. We therefore employ the global vector autoregressive (GVAR) model of Chudik and Fratzscher (2011) and Chudik and Pesaran (2011) which allows for the time-varying component, as well as for bilateral connections, international linkages, and common factors. Moreover, we do not need the persistent component.

The GVAR approach has several advantages. First, we do not rely on components being persistent processes. Second, foreign variables enter the estimation by a weighted matrix such that the bilateral connections are also captured. Specifically, these weights can alter due to the changed expectations of market participants. This technique is especially appropriate for capturing the recent sovereign debt crisis and it outperforms other approaches (Di Mauro and Pesaran 2013). Third, GVAR allows for interdependencies across individual variables within and across units. Even the reduced-form errors are allowed to be cross-sectionally dependent. If needed, the GVAR approach can also capture non-linearities

or thresholds. Furthermore, the introduction of the common variable provides another channel through which influences and linkages enter the bond spread. Therefore, we model bond spreads by domestic, foreign, and common global variables, weighted by their relative fiscal position. Given fiscal problems in one or more Euro-area countries, the interdependence determines the response of each country's spread to those affected by the shocks.

We base our analysis on generalised impulse response functions and variance decomposition. We find that Eurozone Countries are highly interconnected and suffer more from internal shocks. On the other hand, stable Eurozone countries are less vulnerable to shocks from other OECD countries, i.e. U.S. shocks, than other main OECD countries (i.e. Japan). Moreover, our analysis revealed a gap between stable and indebted European countries. Furthermore, we find that the inauguration of the European Monetary Union changed the impact of local shocks: for some 'safer' countries, the impact decreased whereas it increased for the more debt-ridden countries. This leads to a gap within the EMU serious enough to possibly cause the collapse of the common currency.

The remainder of this paper is organised as follows. In Section 2, we provide an overview of the literature on bond spreads, the GVAR approach and international spillovers. In Section 3, we describe the data and perform some pre-analysis of sovereign bond spreads. Section 4 describes the GVAR approach and in Section 5 we present our analysis of the Eurozone bond spreads. Section 6 concludes.

VII.2. Literature Overview

Our paper contributes to the literature in three ways: (1) we contribute to research on international spillovers; (2) we contribute to the analysis of sovereign bond spreads; and (3) we add to work on general vector auto regressive models (GVAR). Spillovers and contagion were already subjects of research before the financial crisis. For example, Ehrmann, Fratzscher and Rigobon (2011b) and Rigobon and Sack (2003b, 2004) use an IV estimator to analyse monetary policy and financial market spillovers. They find strong evidence for spillover effects in both directions. However, Forbes and Rigobon (2002) find no contagion in stock market co-movements. On the other hand, strong evidence of contagious effects of international stock markets after the crisis is provided by Dungey and Martin (2007). More recently, Fratzscher (2009) finds evidence for global transmission of US shocks on foreign exchange markets for both advanced and emerging economies. However, Bekaert, Cho and Moreno (2010) refutes the presence of cross-border contagion in international equity markets. Regarding the transmission of shocks within markets, Diebold and Yilmaz (2009) develop a spillover index. The authors find evidence that return and volatility spillovers across 19 different countries vary widely. Dungey and Martin (2007) analyses contagion across countries and financial markets.

As mentioned, our paper contributes to the literature on bond spreads. Considering Germany as a 'safe haven', the spread to a German Bund reveals the risk an investor faces by buying a specific government bond. Therefore, knowledge about the drivers of bond spreads is of particular interest to policy-makers. As almost all European bonds are issued in Euros, bond spreads no longer include exchange rate or inflationary determinants. Only three main driving factors are of interest: a general risk factor (risk aversion), a liquidity factor, and a fiscal factor (Bernoth, Hagen and Schuknecht 2006; Codogno, Favero and Missale 2003; Geyer, Kossmeier and Pichler 2004). However, how these determinants are measured is less than uniform in the literature. Understanding sovereign bond spreads became more important after the onset of the sovereign debt crisis. In more recent studies, Attinasi, Checherita and Nickel (2009), Barrios, Iversen, Lewandowska and Setzer (2009), Haugh, Ollivaud and Turner (2009) and Manganelli and Wolswijk (2009) find strong evidence for inter-European co-movements, triggered by the factors mentioned above. Moreover, Assmann and Boysen-Hogrefe (2012), Borgy, Laubach, Mésonnier and Renne (2011) and Zoli and Sgherri (2009) prove that European co-movements differ over time. They show that European bond co-movements are less pronounced in bad times such as during the financial debt crisis.

Many studies use the U.S. corporate bond spread as a measure for global risk. Codogno, Favero and Missale (2003) proves, that it is not liquidity but the common risk factor that drives European bond spreads. Their results are supported by Geyer, Kossmeier and Pichler (2004) and Longstaff, Pan, Pedersen and Singleton (2007). More recently, Manganelli and Wolswijk (2009) and Zoli and Sgherri (2009) find evidence for a common factor of European bond spreads. In times of uncertainty, investors become more risk averse and buy safe bonds.

The second determinant of yield differentials is the liquidity risk factor. Distinguishing between liquidity and fiscal factors is important when analysing financial market integration and a country's fiscal position. The results on liquidity as a driving factor of bond spreads are mixed. Bernoth, Hagen and Schuknecht (2006), Codogno, Favero and Missale (2003) and Pagano and Thadden (2004) do not find liquidity to be a significant factor in sovereign bond spreads. On the other hand, a seminal study by Gomez-Puig (2006) proves a positive effect of liquidity on sovereign bond spreads. This finding is supported by Barrios, Iversen, Lewandowska and Setzer (2009) and Gerlach, Schulz and Wolff (2010). Favero, Pagano and Thadden (2010) support the effect of a liquidity factor in sovereign bonds both theoretically and empirically. The authors interact the liquidity factor with a global factor and find evidence that liquidity matters only for a subset of the Euro-area bond markets. On the other hand, Beber, Brandt and Kavajecz (2009) prove that liquidity especially matters in times of market stress.

The third determinant is the fiscal position of the issuer's country of origin. Bernoth, Hagen and

Schuknecht (2004) analyse European bond spreads and find evidence that debt and deficit are the main driving factors of sovereign bond spreads. Hallerberg and Wolff (2008) confirm the impact of the fiscal position although they find it to be less significant after introduction of the Euro. More recently, Bernoth and Wolff (2008) show that 'creative accounting' triggers the spreads more than the debt or deficit. After intensification of the financial crisis in August 2008, financial markets began penalising fiscal imbalances more before than previously and, at the same time, the impact of global investor risk aversion to yield spreads increased significantly. Barrios, Iversen, Lewandowska and Setzer (2009), Haugh, Ollivaud and Turner (2009) and Zoli and Sgherri (2009) show that both the effect of fiscal position and general risk aversion are significantly higher after the financial crisis. However, it might be more plausible to think of coefficients changing gradually over time, rather than having a discrete breakpoint between regimes. The time-varying approach was first undertaken by Assmann and Boysen-Hogrefe (2012) and Pozzi (2008). They find that the debt to GDP ratio is the most important variable in explaining bond spreads. Recently, Bernoth and Erdogan (2012) revealed both the importance of the time-varying approach as well as its results.

We also contribute to the literature on GVAR models. The framework was proposed by Pesaran, Schuermann and Weiner (2004). In general, it is a framework for capturing international linkages and spillovers by also allowing for common factors and time-varying components. It is enhanced by Pesaran (2006) who analysed credit risk. He also used the GVAR model to analyse whether the United Kingdom and Sweden should have adopted the Euro (Dees, Mauro, Pesaran and Smith 2007; Pesaran 2006). A general overview is given in Di Mauro and Pesaran (2013). Bussiere, Chudik and Sestieri (2009) extend the GVAR approach by allowing for the United States' global dominance. Chudik and Fratzscher (2011) and Chudik and Pesaran (2011) advance the GVAR model by including dominant units. The GVAR approach can be used for analysing various types of issues. Dees, Mauro, Pesaran and Smith (2007) use a GVAR approach to study macroeconomic spillovers and linkages within Europe. They use standard macroeconomic time series such as inflation, output, and the interest rate to analyse the potential entry to the Eurozone of the United Kingdom and Sweden in 1999. Hiebert and Vansteenkiste (2010) uses the GVAR approach to analyse the connection of trade and technological shocks on the labour market in an international framework. Instead of the standard trade weights, the authors use sectorial data. Sgherri and Galesi (2009) analyse the transmission of financial shocks, using financial flows as a weight matrix. Chudik and Pesaran (2011) analyse international financial market spillovers and the effect of a common shock on the money market rate in Europe. In a recent approach, Favero and Missale (2012) analyses the potential of a Eurobond. This approach was enhanced in Favero (2013) to analyse government bond spreads in particular. We extend the recent literature by incorporating financial markets into the standard

approach to account for the interconnectedness of financial markets and bond markets. Furthermore, we account for a country's debt position twice, first by using a weight matrix similar to that of Favero (2013) and, second, by combining different macroeconomic indicators into one debt variable by using a principal component analysis.

VII.3. The GVAR Approach

Given that macroeconomic panels often include many countries, but few observation points, standard VAR models do not estimate country linkages and spillovers properly (Chudik and Pesaran 2014). The GVAR approach overcomes this problem by decomposing the underlying large dimensional VARs into a smaller number of conditional models which are linked together via cross-sectional averages.

The GVAR methodology can be summarised as a two-step approach. In the first step, small-scale, country-specific models are estimated conditionally on the rest of the world. These models feature domestic variables and (weighted) cross-section averages of foreign variables which are treated as weakly exogenous. In the second step, these individual country VAR models (from Step 1), along with exogenous variables (VARX), are stacked and solved simultaneously as one large Global VAR model¹.

GVAR in a Nutshell

Step 1

We consider a panel of N countries over time $t \in [1, T]$. Country i is described by k_i variables which are grouped in the $k_i \times 1$ vector x_{it} . $x_t = (x'_{1t} \dots x'_{Nt})$ is the $k \times 1$ vector of all variables of all countries, with $k = \sum_{i=1}^N k_i$. The idea behind GVAR is to estimate the parameters of the small-scale, country-specific variables first. Cross-section averages of foreign variables for country i , denoted by x_{it}^* , are included in the estimation procedure

$$x_{it}^* = \tilde{W}_i' x_t \quad (\text{VII.1})$$

where x_{it}^* is a $k^* \times 1$ vector for $i \in [1, N]$ and \tilde{W}_i is a $k \times k^*$ matrix of country-specific weights². The weights could be used to capture the importance of country j for country i 's economy. This is thus a crucial feature of the GVAR approach, as all foreign variables enter the estimation by the weight matrix. Furthermore, the pooling of the foreign variables by the weight matrix overcomes the above mentioned

¹ A detailed description was recently provided by Chudik and Pesaran (2014).

² The weight matrix contains bilateral information, such as trade. As one country has no trade with itself the matrix takes the value zero in this case. Therefore, the vector x_{it}^* contains only foreign variables, although defined by the entire matrix x_t .

shortcoming of standard VAR procedures. Each foreign variable is aggregated over all foreign countries by the data shrinkage process given by Equation VII.1.

Therefore, the variable x_{it} can be described in the context of a $VARX(p_i, q_i)$ model:³.

$$x_{it} = \delta_{i0} + \delta_{i1,t} + \sum_{l=1}^{p_i} \Psi_{il} x_{i,t-l} + \Lambda_{i0} x_{it}^* + \sum_{l=1}^{q_i} \Lambda_{il} x_{i,t-l}^* + \epsilon_{it} \quad (\text{VII.2})$$

where Ψ_{il} if $l \in [1, p_i]$, and Λ_{il} if $l \in [1, q_i]$, and it represents the $k_i \times k_i$ and $k_i \times k^*$ matrices of unknown parameters. δ_{i0} and $\delta_{i1,t}$ are a trend and a time component. ϵ_{it} is the error term. In total, today's variable x_{it} depends on its previous values as well as foreign influences. The foreign variables are treated as weakly exogenous.

We can rewrite the model in VAR notation by collecting the domestic and foreign variables in one vector $z_{it} = (x'_{it}, x_{it}^*)$ and combining

$$A_{i0} = (I_{k_i}, -\Lambda_{i0}) \quad A_{il} = (\Psi_{il}, \Lambda_{il}) \quad (\text{VII.3})$$

The model given by Equation VII.2 can then be expressed as

$$A_{i0} z_{it} = \delta_{i0} + \delta_{i1,t} + \sum_{l=1}^p A_{il} z_{i,t-l} + \epsilon_{it} \quad (\text{VII.4})$$

where $p = \max(p_i, q_i)$ and $\Lambda_{il} = 0$ and $\Psi_{il} = 0$ if $l > q$ and $l > p$, respectively. As we account for only the country-specific models in the first step, variables with an asterisk are treated as weakly exogenous.

Global Variables

In addition to the country-specific variables, this approach allows for the inclusion of global variables such as commodity prices. These variables are equal for all countries (in contrast to the foreign variables). Equation VII.3 can be augmented by

$$x_{it} = \delta_{i0} + \delta_{i1,t} + \sum_{l=1}^{p_i} \Psi_{il} x_{i,t-l} + \Lambda_{i0} x_{it}^* + \sum_{l=1}^{q_i} \Lambda_{il} x_{i,t-l}^* + D_{i0} \omega_t + \sum_{l=1}^{s_i} D_{il} \omega_{t-l} + \epsilon_{it} \quad (\text{VII.5})$$

where ω_t are the common variables which can be treated as weakly exogenous (similar to the foreign variables). D_{il} is a $k_i \times k_i$ matrix of unknown parameters. ω_t can include lagged variables or influences

³ A VARX model is a standard VAR model including exogenous variables

of the foreign economy; in this case, it is

$$\omega_t = \sum_{l=1}^{p_w} \Psi_{wl} \omega_{t-l} + \sum_{l=1}^{q_w} \Lambda_{\omega l} x_{i,t-l}^* + \eta_{\omega,t}$$

where $\eta_{\omega,t}$ is an error term. The model described in Equation VII.4 can be estimated individually from the rest of the world if no unobserved common factors are given. However, the model becomes complex if unobserved factors are given, as in Equation VII.5. Dees, Mauro, Pesaran and Smith (2007) and Pesaran (2006) show that f_t can be proxied by the observed common factors d_t and variables x_{it} if the number of countries is sufficiently large. Conditional on the given domestic parameters, the remaining parameters of the *VARX* model are consistently estimated by ordinary least squares regressions. By construction, we can then identify a time-varying common component that differs in intensity between countries. We therefore capture the time-varying component of international bond and stock spreads and the international linkages between markets and countries.

Step 2

Once the individual country models are estimated, all the $k = \sum_{i=0}^N k_i$ endogenous variables of the global economy, collected in the $k \times 1$ vector $x_t = (x'_{0t}, \dots, x'_{Nt})$, need to be solved simultaneously. The weight matrix W_i is defined as $W_i = (E'_i \tilde{W}_i)'$, where E_i is the $k \times k_i$ dimensional matrix that selects $x_{it} = E'_i x_t$. Given W_i , the matrix of country-specific weights, it is

$$z_{it} = (x_{it}, x_{it}^*)' = W_i x_t \quad (\text{VII.6})$$

Using the definition of z_{it} , the weight matrix W_i , and the notation from Equation VII.4, the stacked model can be written as

$$A_{i0} W_i x_t = \delta_{i0} + \delta_{i1,t} + \sum_{l=1}^p A_{il} W_i x_{t-l} + \epsilon_{it} \quad (\text{VII.7})$$

$$\Leftrightarrow G_0 x_t = \sum_{l=1}^p G_l x_{t-l} + \epsilon_t \quad (\text{VII.8})$$

where $\epsilon_t = (\epsilon'_{1,t} \dots \epsilon'_{N_t})$ and $G_l = ((A_{1,l} W_1)' \dots (A_{N,l} W_N)')$. If G_0 is invertible, this yields into

$$x_t = \sum_{l=1}^p F_l x_{t-l} + G_0^{-1} \epsilon_t \quad (\text{VII.9})$$

with $F_l = G_0^{-1} G_l$, $\forall l \in [2, p]$.

Global Variables

Stacking the global variable is quite similar. We include $z_{it} = W_i x_t$ in Equation VII.5, the country-specific VARX model which includes the common variable ω_t , defined in Equation VII.6. We define $y_t = (\omega'_t x'_t)$. The GVAR is then similarly stacked into

$$G_{y,0} y_t = \sum_{l=1}^p G_{y,l} y_{t-l} + \epsilon_{y,t} \quad (\text{VII.10})$$

where $\epsilon_{y,t} = (\epsilon'_t, \eta'_{wt})$,

$$G_{y,0} := \begin{pmatrix} I_{mw} & 0_{mw \times k} \\ D_0 & G_0 \end{pmatrix}, \quad G_{x,l} := \begin{pmatrix} \Psi_{wl} & \Lambda_{wl} \tilde{W}_w \\ D_l & G_l \end{pmatrix}$$

$\forall l \in [2, p]$. Furthermore $D_l = (D'_{1l}, \dots, D'_{Nl})'$, $\forall l \in [0, p]$ and $p = \max_i \{p_i, q_i, s_i, p_w, q_w\}$ with $D_{il} = 0$ for $l > s_i$, $\Psi_{wl} = 0$ for $l > p_w$, and $\Lambda_{wl} = 0$ for $l > q_i$. If G_0 is invertible then $G_{y,0}$ is invertible (Chudik and Pesaran 2014). The model can then be written as

$$y_t = \sum_{l=1}^p F_{y,l} y_{t-l} + G_{y,0}^{-1} \epsilon_{y,t} \quad (\text{VII.11})$$

where $F_{y,l} = G_{y,0}^{-1} G_{y,l}$.

VII.4. Data

Our main goal is to analyse European bond spreads and we thus focus on European countries. We account for over 80 percent of European GDP by including Germany, France, Italy, the Netherlands, and Spain. To account for the effects of the sovereign debt crisis on troubled countries, we also include Greece, Ireland, and Portugal. To account for the open economy, we include the remaining G7 countries which are Canada, the United States, the United Kingdom, and Japan. Our sample starts in 1993:Q1 and ends in 2013:Q4, thus capturing the onset of the Eurozone and its subsequent development. Furthermore, we analyse the time period 1999:Q1 to 2013:Q4 separately to discover the effect of the common currency.

The data on yield spreads were provided by Thomson Financial Datastream. We compare government bonds issued by the nine EU countries and the three remaining G7 countries between 1993 and 2013 which are denominated in Deutsche Marks before 1998 and in Euros thereafter.⁴ We normalise all data into a quarterly base. In the case of daily bond spreads, we use the quarterly mean.⁵ In the case of annual

⁴ To compare the variables we converted the bonds into Euros.

⁵ As a robustness check we used end of period values, results are similar and will be provided upon request.

data, we interpolate the data using cubic splines. One exception is the weight matrix as this accounts only for annual changes. A detailed overview of the data is given in Table VII.1.

All variables are expressed in differences from the corresponding figures of the benchmark country, Germany. For example, we take the difference in GDP growth with respect to Germany as a proxy for GDP, and we take the difference in fiscal fundamentals with respect to Germany for the weight matrix.

As discussed above, the literature agrees on three driving factors of government bond spreads: a country's default risk, a liquidity risk, and a common risk aversion. We contribute a fourth factor: a financial market risk of spillovers. In this section, we describe the factors in detail. A country's risk of default is commonly measured by fiscal variables ⁶.

Default Risk

We expect that if a country's fiscal position deteriorates relative to the benchmark country, the bond spread increases, as markets will demand a higher default risk premium. Credit risk is estimated by using standard fiscal variables such as the debt to GDP ratio or the deficit to GDP ratio. The list of authors who applied fiscal measures as credit risk indicator is extensive: Aizenman, Hutchison and Jinjark (2013), Beirne and Fratzscher (2013), Bernoth and Erdogan (2012), Favero and Missale (2012), Favero (2013), Manganelli and Wolswijk (2009) and Schuknecht, Hagen and Wolswijk (2010) use the debt to GDP ratio to cover the default risk. Bernoth and Erdogan (2012) and Schuknecht, Hagen and Wolswijk (2010) also include the deficit to GDP ratio to measure the default risk of a state. Other authors such as Beirne and Fratzscher (2013), De Grauwe and Ji (2012) and Lane (2012), take the current account deficit or the fiscal balance instead. Moreover, Gibson, Hall and Tavlás (2012) uses expenditure and revenue relative to the GDP to account for fiscal position.

Since inauguration of the Maastricht Treaty, deficit and debt have become of major political interest. Governments tend to engage in 'creative accounting' to reach the Maastricht target. We believe that all fiscal variables have a significant impact on government bond spreads. To use the information provided by all these variables while, at the same time, keeping the number of variables small in order to retain sufficient degrees of freedom, we conduct a principal component analysis of the fiscal variables and extract the dominant patterns. The first component already explains 80% of the variance in the variables. We therefore believe that our fiscal stance variable captures all relevant information. Specifically, we employ government revenues and expenditures, the structural balance, (primary) deficit, the account balance, and net gross debt, all of which are expressed in terms of the national GDP. The explained

⁶ (i.e. Assmann and Boysen-Hogrefe (2012), Attinasi, Checherita and Nickel (2009), Barrios, Iversen, Lewandowska and Setzer (2009), Bernoth, Hagen and Schuknecht (2004), Bernoth, Hagen and Schuknecht (2006), Borge, Laubach, Mésonnier and Renne (2011), Codogno, Favero and Missale (2003), Geyer, Kossmeier and Pichler (2004), Haugh, Ollivaud and Turner (2009), Manganelli and Wolswijk (2009) and Zoli and Sgherri (2009)).

part is shown in Table VII.2. To avoid the difficulties inherent in using different data sources, we rely on the AMECO forecast. By using the forecast instead of the actual variable we account for the effect of expectations. Moreover, these variables are less subject to creative accounting. This procedure is in line with that of Beirne and Fratzscher (2013), Bernoth and Erdogan (2012) and Schuknecht, Hagen and Wolswijk (2010), among others. However, data are only provided on an annual basis. Therefore, we interpolate the data to quarterly data by using cubic splines.

Market Liquidity

Market liquidity can be measured by direct means, such as the trading volume or bid-ask spreads, or by indirect measures, such as the amount of outstanding debt securities relative to market size. Gomez-Puig (2006) shows that direct and indirect measures are closely related. She compares bid-ask spreads and the amounts of outstanding debt securities and find that both measures are significant drivers of bond spreads. Codogno, Favero and Missale (2003) compare bid-ask spread, trading volume, and turnover ratio and find that trading volume is the best performing liquidity indicator. Bernoth, Hagen and Schuknecht (2004) also use the size of government bond markets and find a significant effect of this variable on the yield differentials of Euro-area countries. A drawback of bid-ask spreads as a liquidity measure is that they are not truly exogenous. Dunne, Moore and Portes (2006) proves that bid-ask spreads depend on their marketplace features. We join those researchers who use market size, measured by the amount of outstanding debt securities relative to overall market size, as a liquidity measure. Data are available on a quarterly basis and are taken from the Bank for International Settlements Database.

Risk-Aversion

Finally, we use the corporate bond yield spread as a proxy for general investors' risk aversion which is a conventional measure in the related literature (Attinasi, Checherita and Nickel 2009; Barrios, Iversen, Lewandowska and Setzer 2009; Bernoth and Erdogan 2012; Codogno, Favero and Missale 2003; Haugh, Ollivaud and Turner 2009). The corporate bond spread represents the spread between low-grade corporate bonds (Baa) and high-grade bonds (Aaa). In times of greater uncertainty, the corporate bond yield spread widens because of a shift in investor preference from riskier corporate bonds to safer government bonds. Thus, assuming that the benchmark country, Germany, is a 'safe haven' among EMU countries, we expect a positive relationship between the corporate bond yield spread and sovereign bond yield differentials. Data are taken from the Federal Reserve Database. For example, after the shock of Lehman Brothers default, risk aversion increased and high-ranked bonds were bought. This led to higher yields for low-graded bonds and the spread increased. Furthermore, in a similar manner, we include the CBOE

VIX index of market volatility. Data are provided by the CBOE website (Beber, Brandt and Kavajecz 2009; Favero, Pagano and Thadden 2010).

Financial Markets

Although the interaction of monetary policy and financial markets has been studied thoroughly (i.e., the seminal paper of Rigobon and Sack (2003a)), very little research has been undertaken to analyse stock markets as a driver of sovereign bond spreads. Annaert, De Ceuster, Van Roy and Vespro (2013) and Grammatikos and Vermeulen (2012) show some evidence of the influence of stock markets on sovereign CDS spreads. Looking from an opposite perspective, Kaminsky and Schmukler (2001) find that sovereign ratings affect stock markets. However, we assume highly interacted markets and possible spillovers from stock markets to bond markets and thus include national stock indices in our analysis. In particular, we use the S&P 500 in case of the United States, the TSX in case of Canada, the CAC40 in case of France, the FTSE in case of England, the IBEX in case of Spain, the Nikkei in case of Japan, the AEX in case of the Netherlands, the FTSEMIB in case of Italy, the ASE in case of Greece, the ISEQ in case of Ireland, the PSI in case of Portugal and the DAX as German benchmark.

Control Variables

Sovereign risk may also depend on macroeconomic fiscal and monetary policy. Min (1998) argues that inflation can be interpreted as a broad measure of political discipline. Therefore, in line with Aizenman, Hutchison and Jinjara (2013) and Antonello and Ehrmann (2012), we control for inflation. Inflation is expressed as the change in the quarterly CPI relative to the same period in the previous year.

The Weighting Scheme

The weighting scheme variables, for each country are fiscal spreads which are the weighted average of other countries' spreads, where weights depend on the distance, measured in terms of differences in fiscal fundamentals, that separates countries. Di Mauro and Pesaran (2013) use bilateral trade as a weighting scheme. Other scholars have extended this idea by using weighting schemes based on financial flows or regional patterns. Galesi and Sgherri (2009) propose a GVAR with weights based on cross-country financial flows, while Vansteenkiste and Hiebert (2011) use weights based on the geographical distance between regions. Hiebert and Vansteenkiste (2010) adopt weights based on sectoral input-output tables across industries. Most recently, Favero (2013) uses the fiscal stance relative to Germany to analyse government bond spreads.

We follow Favero (2013) and contribute to the GVAR literature by using a fiscal variable as the weighting scheme. Specifically, we use each country's deviation from the 60% goal of the Stability and Growth Pact relative to that of the benchmark country. As this ratio is not part of the principal component analysis, there is no direct issue of heterogeneity. As a robustness check, we use the deficit to GDP ratio and the impact of GDP growth on debt as instruments for the excessive deficit procedure. All data are taken from the AMECO database. Our scheme is similar to that of Favero (ibid.). In an additional test of robustness, we also conduct the analysis using the standard trade weight scheme.

Modelling Bond Spreads

Figures VII.3 and VII.3 show evidence of co-movement for major macroeconomic and financial variables, especially for the major international stock indices, the logged industry index, logged GDP, and bond spreads. Bond spreads have co-moved since inauguration of the European Union; however, at the onset of the financial crisis, this changed. More recently, they have tended to co-move again. We also observe co-movements in the fiscal variables; debt to GDP ratios highly co-moved with German debt to GDP ratios until 2007. However, the current account to GDP ratio shows less co-movement. Furthermore, stock markets were strongly linked before and after the financial crisis.

We follow Di Mauro and Pesaran (2013) and Dees, Mauro, Pesaran and Smith (2007) and employ a global vector auto-regressive model (GVAR). The GVAR is designed to treat all country-specific variables x_{it} and observed global factors endogenously. Normally, bond spreads are considered persistent processes with a long-run equilibrium (Favero 2013). However, the static environment does not explain the heterogeneity observed in the bond spreads. The GVAR approach is more flexible and can take into account time-varying co-movements. We compute a vector of variables, consisting of domestic and foreign and common factors, both at the same time and lagged.

VII.5. Estimation

Our first focus is on the overall impulse responses across country groups in order to identify general, overarching trends and differences⁷. The first subsection of this section presents findings from the impulse response functions of the GVAR; the second outlines the results of the forecast error variance decomposition.

To arrive at a first impression of the spillover effects in the model, we control the contemporaneous

⁷ We treat Greece separately as it is different in several ways from other indebted countries in the Eurozone. First of all, it has defaulted on its debt many times before, therefore a lenders confidence in getting his money back is troubled. Second, it has joined the Eurozone later than the other countries, because it was denied membership in the first place. Third, Greece is relatively higher indebted than other European countries and on the top faces more corruption and cronyism.

effects of foreign variables on domestic counterparts, given in Table VII.4. The results suggest that there are significant spillovers between markets. We observe significant spillovers from bond markets to the national bond market for most countries. Similarly, stock market spillovers are significant for Canada, France, Japan, the Netherlands, and Portugal. Liquidity effects spill over for Canada, France, Japan, the Netherlands, and Portugal, and fiscal stance is also important for these countries. All in all, the results support our expectation regarding size and significance. Specifically, we find strong evidence for market and national spillovers. Given the power of estimation for the individual models, shown in Table VII.5, the model captured fiscal variables very well, and, except in the case of the United States, bonds, stocks, and liquidity are also captured well. Therefore, we are confident that our model captures the major factors driving bond spreads.

VII.5.1. Impulse Response Functions

Figures VII.6 to VII.24 show the generalised impulse response function (GIRFs) for the Eurozone countries, European crisis countries, and Greece, and rest of the OECD countries, where impulse responses are unweighted averages of all countries within the group. The first figure shows reactions to a U.S. stock market shock, and makes it obvious that troubled countries react more strongly to this sort of shock than Eurozone countries or the rest of the industrialised countries. A shock on the U.S. stock market causes sovereign bond spreads to first increase and then slowly decrease. The reaction among the industrialised world is more pronounced than within the non-crisis Eurozone countries which might indicate that the 'non-bailout clause' is not reliable, or that within the Eurozone, these countries are considered similarly risky. The stock market reaction is similar. Stock market spreads increase directly due to the shock and then return to 'normal'. However, there is variance in the return process. It is notable that the Greek stock market is considered less risky than the Greek bond market. Therefore, the shock is less pronounced on the stock market than on the bond market. Similar to what occurs in the bond market, reactions of the money market rate are more pronounced in crisis countries and the rest of the world than in the Eurozone. However, interpretation of this finding is difficult as European countries have shared the same money market rate since the introduction of the Euro.

We then compare a U.S. shock on the stock market to a Greek shock on the stock market. We observe a much more pronounced effect in Greece and spillovers to other European crisis countries. However, there is no notable effect on the rest of the Eurozone or other industrialised countries. This is particularly the case for bond prices but also for stock prices and a global volatility shock. Especially in the case of the stock market crisis, Greek stock spreads continue to be deeper than they were at the beginning of the crisis.

A shock on the global volatility index can be interpreted as an increase in risk aversion. As market participants become more cautious, the bond spread in troubled countries increases; therefore, these countries must pay higher interest rates to obtain access to money. There are only minor effects in industrialised countries. Effects on the stock and money markets are similar. Especially on the stock market, there are effects for both industrialised and crisis countries. A shock to volatility causes a reaction in only the troubled bond markets, implying that (negative) spillovers are more pronounced for those countries that are already in debt. However, there are no noticeable spillovers in the rest of the Eurozone and only minor reactions in the rest of the world. The latter are driven by US effects as this was the origin of the shock. In contrast to the bond market, however, there are significant spillovers to all countries on the stock market. As we already found significant contemporaneous effects between the markets, this is in line with our expectations. In this case, the effect on the rest of the world is even stronger than it is in Greece. Except for the Eurozone, we observe similar effects regarding the money market. In the event that the volatility shock originated in Greece, the effects on most markets are less pronounced or even insignificant.

A liquidity crisis is characterised by the inability of traders to sell some of their assets. On the other hand, liquidity shocks can also be manifested as an inflow of market liquidity made with the intent of increasing the number of trading partners. For example, to increase liquidity and diminish investor risk, monetary policy-makers engage in quantitative easing (QE). In this context, a shock in liquidity also represents unconventional monetary policy action. When QE is conducted in the United States, Greek bond markets react strongly; however, other European bonds, as well as bonds from other OECD countries, also react to unconventional US monetary policy. Only European bonds seem to react less strongly. On the other hand, QE has a significant impact on all stock markets and spills over to monetary policy-makers worldwide.

VII.5.2. Variance Decomposition

We now turn to the results of the variance decomposition. Table VII.6 reports results for the importance of US shocks illustrating selected variables; whereas Table VII.7 reports similar information for spillovers from Greece. We show the average percentage contribution to the total variance of major shocks across all groups of countries. Table VII.8 shows an extract of the variance decomposition since formation of the European Monetary Union.

Some of the results are particularly noteworthy. First, as expected, for most variables, U.S. shocks explain more market volatility than Greek shocks. Furthermore, the stable Eurozone bond markets are less vulnerable to US shocks. In contrast, there are contagious effects from U.S. shocks to non-European

OECD bond markets. It is striking that U.S. monetary policy, represented by the interbank rate, explains more of the bond market volatility for the European crisis countries than it does for the OECD countries or the stable Eurozone countries. This finding implies that Greece, Spain, and other highly indebted countries are more affected by Fed policy than Germany or the Netherlands.

A U.S. monetary policy shock has a strong impact on highly indebted Eurozone countries, but the effect diminishes rather quickly. Thus, Fed policy appears to have an intense but short effect on the bonds of highly indebted European countries. In total, we observe that stable countries are only affected by US stock markets, but countries in crisis are much more driven by all types of US influence.

Furthermore, US bond market shocks have a stronger impact on non-European bond markets; on the other hand, however, European bond markets are likely to be affected by European bond market shocks. Thus, there are few spillover effects within international bond markets, but strong spillover effects within European bond markets. It is particularly striking that the effect of a Greek bond shock diminishes rather quickly in Greece, but its contagious effects on other European crisis countries increase tremendously over time. In general, there are few spillover effects from Greece to stable European countries and other OECD countries. However, a Greek stock market shock has slightly more impact on European bonds than a US stock market shock.

Comparing results from the sample since 1993 with the one starting in 1999, we find that there was a change in the factors behind stock and bond market shocks in all countries after inauguration of the Euro. We find, in this later period, that stock market volatility is less driven by US stock market shocks, and more by US volatility shocks. Exceptions are the European crisis countries which now react even more strongly to both kinds of shocks. In contrast, it seems that Greek shocks affect European bonds and stocks, particularly those of the more indebted countries, even more strongly after inauguration of the common currency.

VII.6. Conclusion

Since the financial crisis, much research has been undertaken to understand the severe impact of the crisis on the real economy and how it spills over to other countries. We contribute to this literature by analysing the spillovers of financial markets, monetary policy and sovereign bonds. We focus on shocks from the US and Greek financial markets to the bond, stock and money markets. The empirical evidence is derived from a Global VAR approach which allows us to deal with shocks and their transmission, the dimensions of eleven countries and spillover effects. The GVAR models the changing interdependence among spreads by making each country's spread a function of global spreads with a time-varying composition. Specifically, global spreads for each country are defined as the weighted average of spreads for

all the other countries. Weights are determined by the distance between countries, measured in terms of differences in the expected debt to GDP ratio. This method captures fluctuations in spreads due to fiscal shocks, financial market shocks or monetary shocks.

Analysis of the impulse response functions suggests that the reactions of troubled countries are stronger than those of the Eurozone or the rest of the industrialised countries. A shock on the US stock market causes sovereign bond spreads to first increase and then slowly decrease. The reaction among the industrialised world is more pronounced than within the non-crisis Eurozone countries which might indicate that the 'non-bailout clause' is not reliable or that within the Eurozone these countries are considered similarly risky. Our findings suggest that stock and money market shocks have a more pronounced effect on the variables whereas the effects of volatility and liquidity shocks are more persistent. We conclude that shocks to the instruments, such as stocks, are more severe, whereas shocks to the driving factors of the instruments, such as liquidity, are more persistent. Furthermore, spillovers from the United States are bigger than those from Greece. More specifically, we find that impulse response functions and the variance decomposition reveal a huge gap within the EMU. On the one hand, the spreads of robust Eurozone countries, such as the Netherlands, react less to shocks from abroad than the rest of the world. However, the troubled countries, such as Greece or Spain, react more strongly than other country groups. This finding implies that markets are not congruent within Europe. Considering that the issuance of Eurobonds is currently under consideration, the results of the paper are highly relevant. The optimal market price would be the average of the prices of sound and indebted European countries. However, this price would not be optimal for either as the yields of these Eurobonds would be too high for sound European countries on the one hand and too low for the highly indebted Eurozone countries on the other.

VII.7. Figures and Tables

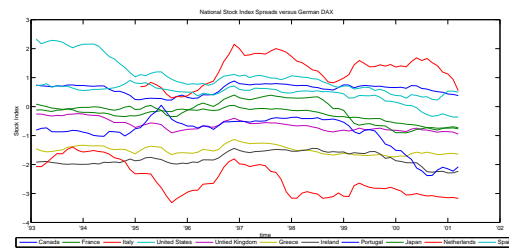


Figure VII.1.. Co-movement of real and financial Euro variables.

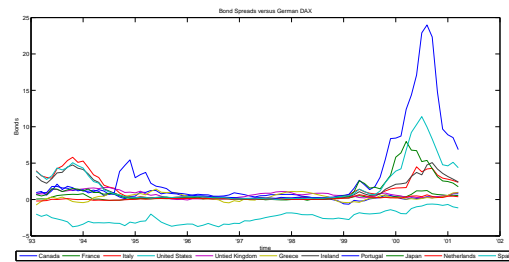


Figure VII.2.. Co-movement of real and financial Euro variables.

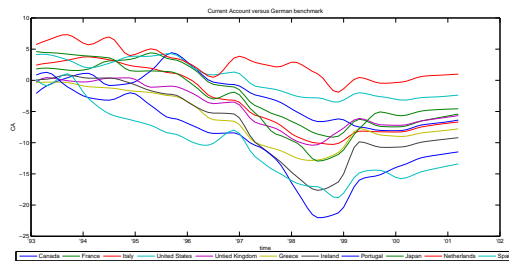


Figure VII.3.. Co-movement of real and financial Euro variables.

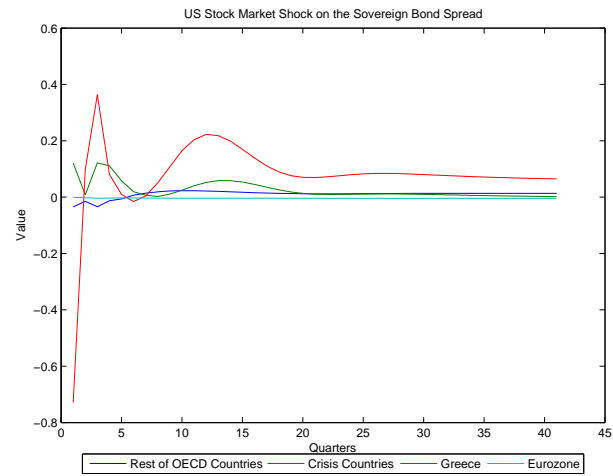


Figure VII.4.. Shock on the US Stock Market

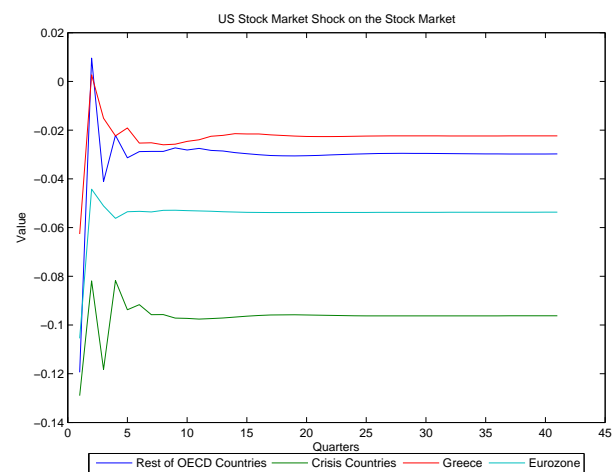


Figure VII.5.. Shock on the US Stock Market

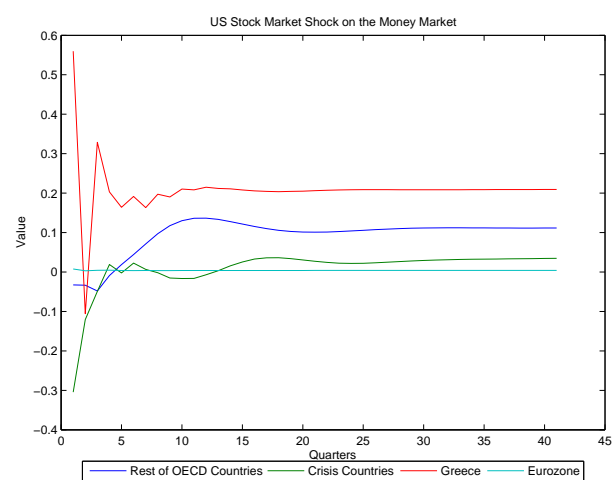


Figure VII.6.. Shock on the US Stock Market

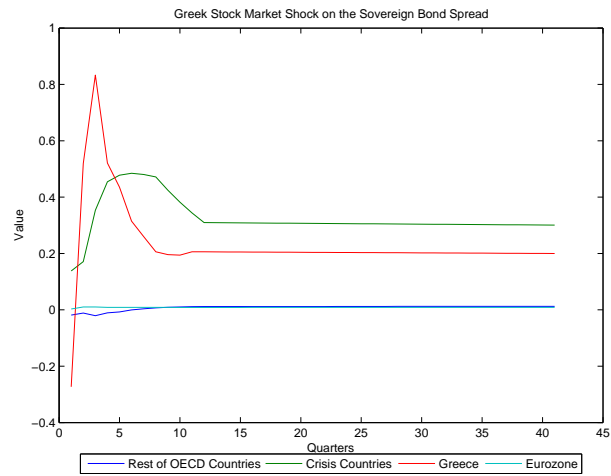


Figure VII.7.. Shock on the Greek Stock Market

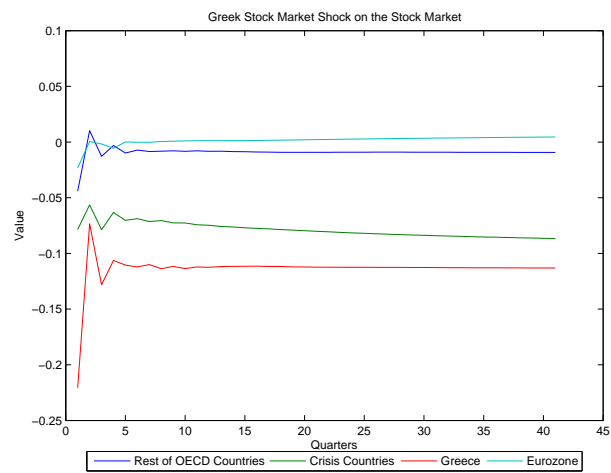


Figure VII.8.. Shock on the Greek Stock Market

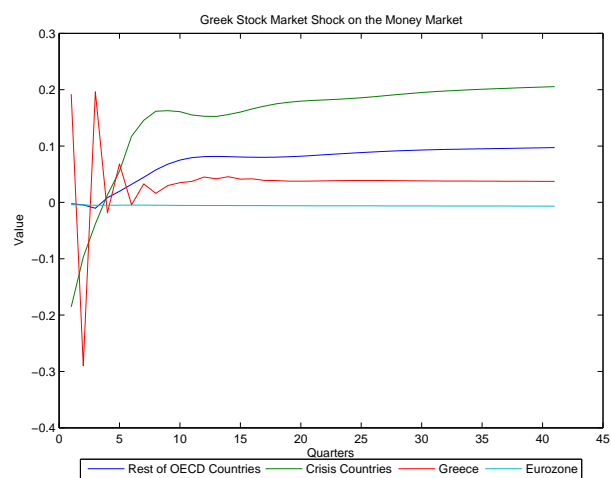


Figure VII.9.. Shock on the Greek Stock Market

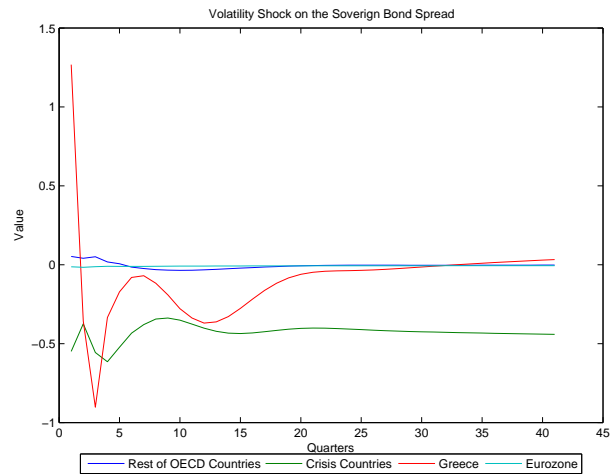


Figure VII.10.. Shock on Volatility, starting in the United States

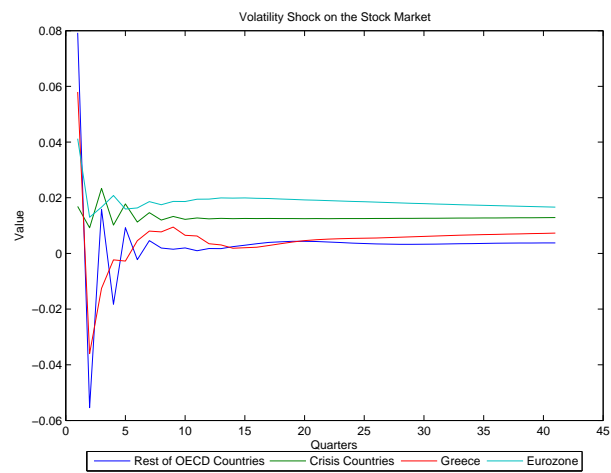


Figure VII.11.. Shock on Volatility, starting in the United States

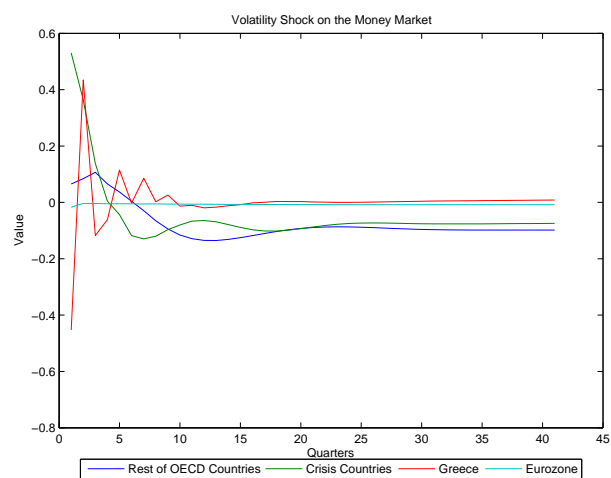


Figure VII.12.. Shock on Volatility, starting in the United States

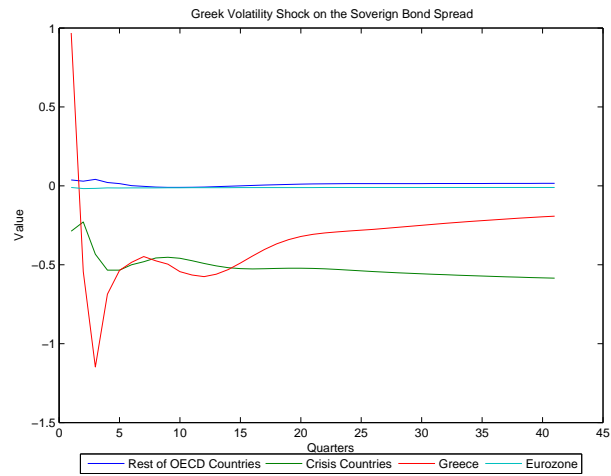


Figure VII.13.. Shock on Volatility, starting in Greece

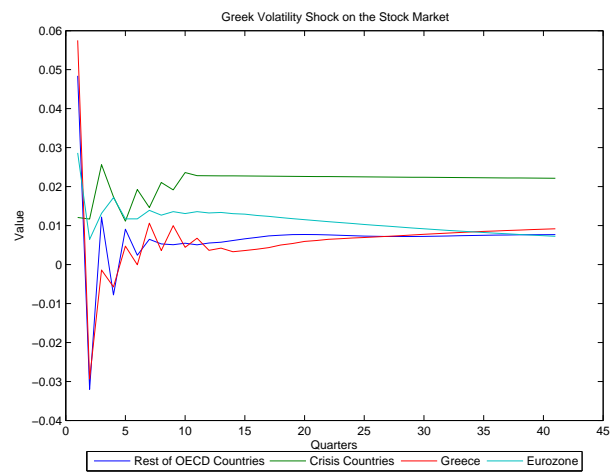


Figure VII.14.. Shock on Volatility, starting in Greece

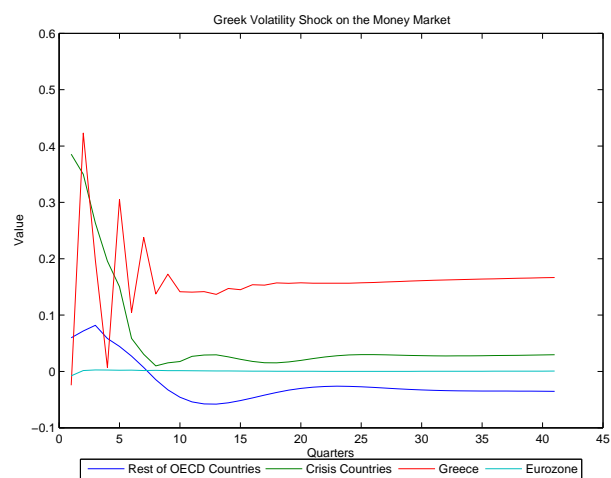


Figure VII.15.. Shock on Volatility, starting in Greece

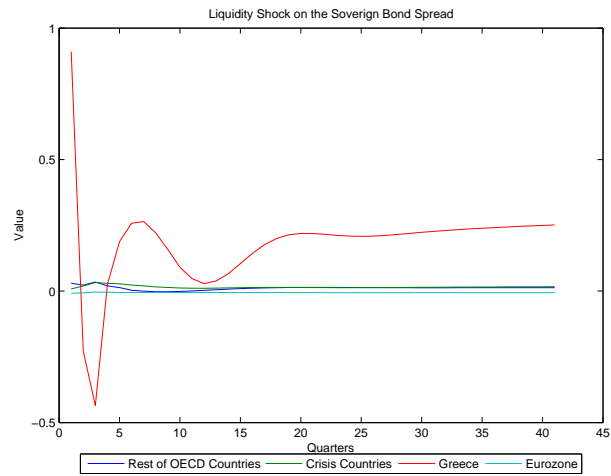


Figure VII.16.. Shock on Liquidity, starting in the United States

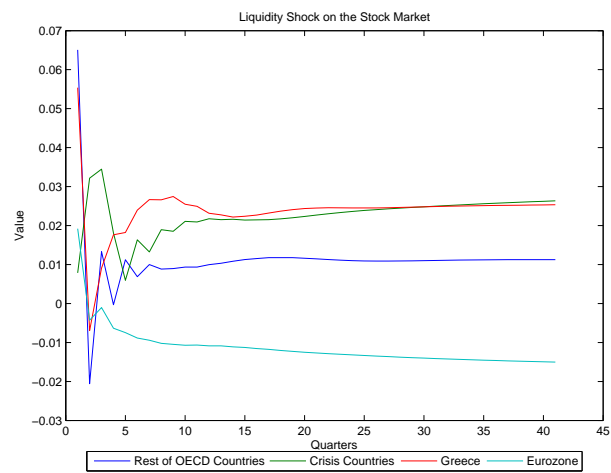


Figure VII.17.. Shock on Liquidity, starting in the United States

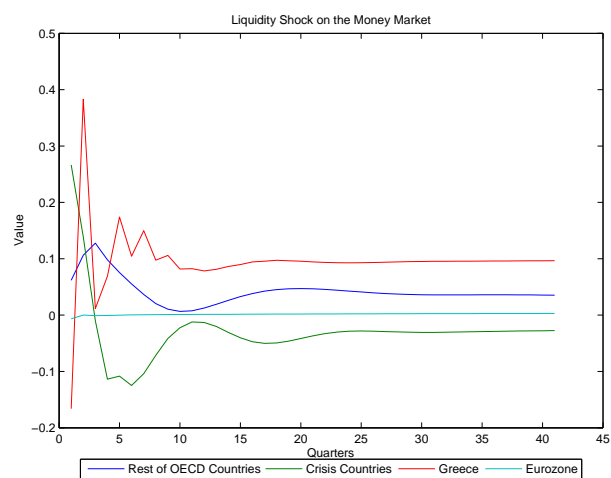


Figure VII.18.. Shock on Liquidity, starting in the United States

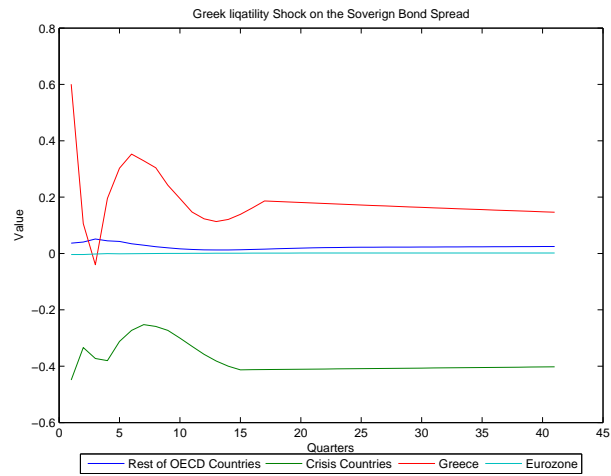


Figure VII.19.. Shock on Liquidity, starting in the Greece

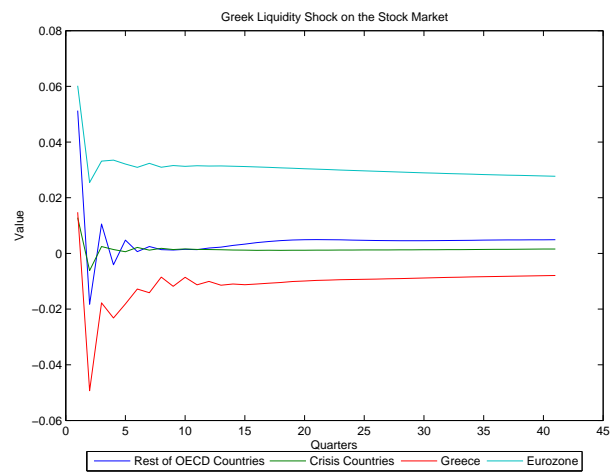


Figure VII.20.. Shock on Liquidity, starting in the Greece

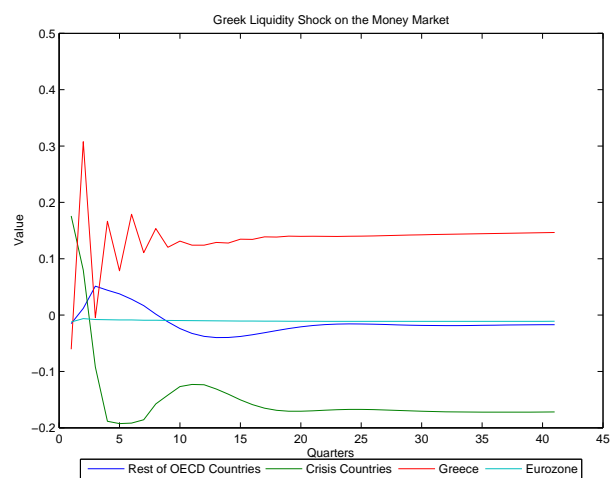


Figure VII.21.. Shock on Liquidity, starting in the Greece

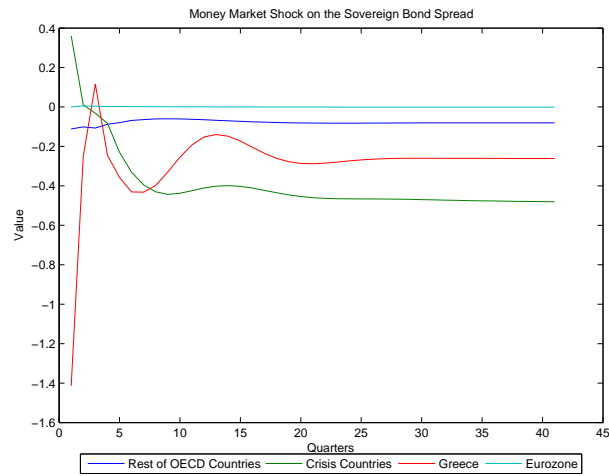


Figure VII.22.. Shock on the Money Market, starting in the United States

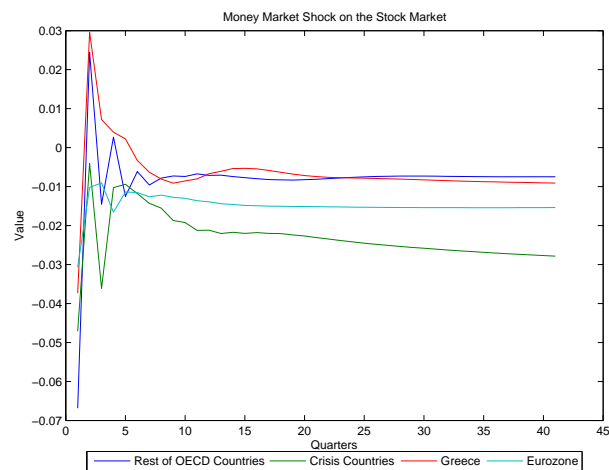


Figure VII.23.. Shock on the Money Market, starting in the United States

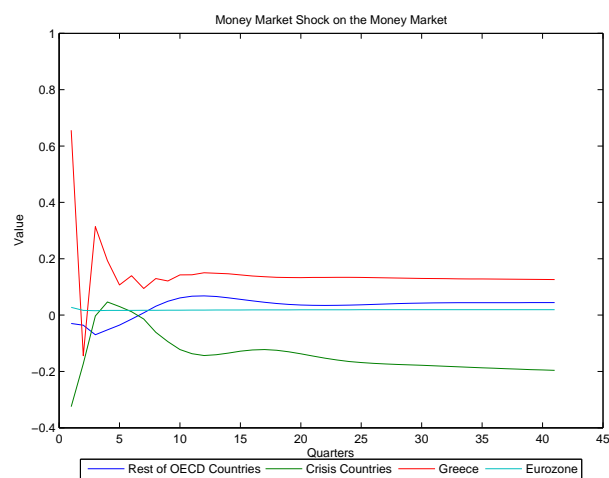


Figure VII.24.. Shock on the Money Market, starting in the United States

Table VII.1.. Data Sources

Variable	Category	Data Source	Frequency
Sovereign Bond Spread	Bond	Reuters	Daily
Stock Index	Financial	Reuters	Daily
Money Market Rate	Monetary Policy	Reuters	Daily
Inflation	Monetary Policy	National Central Banks	Quarterly
Industry Index	Economic Stance	OECD Database	Quarterly
Debt Outstanding	Liquidity	BIS Database	Quarterly
Fiscal Stance	Fiscal Stance	OECD, own calculation	Annual
Baa-Aaa Spread	Risk Aversion	FRED Database	Daily
CBOE VIX Index	Risk Aversion	CBOE	Daily
Bilateral Trade	Weight Matrix	OECD	Annual
FDI	Weight Matrix	OECD	Annual
EDP	Weight Matrix	Eurostat	Annual

Table VII.2.. Principal Component Analysis

Country	Explained	Country	Explained
Canada	87.8	Netherlands	85.9
France	97.6	Portugal	96.8
Greece	93.3	Spain	80.5
Italy	91.1	United Kingdom	95.7
Ireland	85.6	United States	93.0
Japan	99.4		

Table VII.3.. Descriptive Statistics for Sovereign Bond Spreads

	JB	Kurtosis	Skewness	Mean	Min	Max	StDev
Canada	0	3.49	0.17	0.58	-0.64	1.80	0.48
France	1	4.83	1.49	0.25	-0.12	1.23	0.30
Italy	1	2.89	1.11	1.47	0.12	5.80	1.63
Japan	1	2.37	0.54	-2.50	-3.75	-0.62	0.86
United Kingdom	0	2.26	0.36	0.69	-0.06	1.65	0.45
United States	0	2.31	0.07	0.32	-0.75	1.44	0.47
Spain	1	2.54	0.99	1.29	0.01	5.08	1.53
Greece	1	8.50	2.43	3.29	0.15	23.98	5.33
Ireland	1	6.61	2.07	1.23	-0.10	7.97	1.82
Netherlands	1	3.53	0.85	0.13	-0.20	0.67	0.18
Portugal	1	5.37	1.70	1.00	0.00	11.39	2.70

Table VII.4.. Contemporaneous Effects

	bonds	stocks	industry	liquidity	fiscal
Canada	0.05*	0.10*	-0.05*	0.13*	0.01*
	(0.02)	(0.05)	(0.08)	(0.03)	(0.01)
France	0.10*	0.20*	0.05*	0.20*	0.00*
	(0.02)	(0.06)	(0.08)	(0.03)	(0.02)
Italy	-0.05		0.05	-0.19	0.02
	(0.13)	(0.00)	(0.07)	(0.28)	(0.02)
Japan	0.41*	0.76*	0.11*	1.72*	0.41*
	(0.10)	(0.17)	(0.25)	(0.42)	(0.09)
UK	-0.03	0.57	0.50	-1.67	0.00
	(0.02)	(0.09)	(0.19)	(0.16)	(0.03)
US	-0.01	0.34	-0.02	-0.71	0.01
	(0.02)	(0.08)	(0.09)	(0.19)	(0.01)
Spain	-0.03	0.53	0.41	0.77	0.02
	(0.05)	(0.10)	(0.18)	(0.06)	(0.05)
Greece	1.28	0.84	0.96	-1.08	0.14
	(0.99)	(0.17)	(0.17)	(0.45)	(0.15)
Ireland	0.03	0.32	0.23	0.58	-0.01
	(0.04)	(0.07)	(0.19)	(0.10)	(0.02)
Netherlands	0.05*	0.88*	0.77*	-0.24*	0.02*
	(0.02)	(0.24)	(0.26)	(0.07)	(0.05)
Portugal	0.05*	0.06*	-0.15*	0.31*	0.00*
	(0.02)	(0.03)	(0.07)	(0.06)	(0.00)

* 5% significance level, values in brackets are standard errors

Table VII.5.. Power of explanation for the individual estimations

Country	Variable	R^2	\bar{R}^2	Country	Variable	R^2	\bar{R}^2
Canada	bond	0.57	0.41	US	bond	0.30	0.03
	stock	0.65	0.52		stock	0.63	0.49
	money	0.64	0.51		money	0.71	0.61
	cpi	0.40	0.18		cpi	0.48	0.29
	industry	0.33	0.08		industry	0.47	0.27
	liquidity	0.49	0.29		liquidity	0.35	0.10
	fiscal	0.96	0.94		fiscal	0.93	0.91
	vix	0.56	0.39		vix	0.70	0.59
France	bond	0.48	0.31	Spain	bond	0.77	0.70
	stock	0.67	0.56		stock	0.74	0.65
	cpi	0.35	0.13		cpi	0.33	0.10
	industry	0.61	0.47		industry	0.43	0.23
	liquidity	0.63	0.51		liquidity	0.85	0.80
	fiscal	0.93	0.90		fiscal	0.97	0.96
	vix	0.72	0.62		vix	0.72	0.62
Italy	bond	0.48	0.32	Greece	bond	0.83	0.77
	cpi	0.24	0.01		stock	0.63	0.51
	industry	0.84	0.79		cpi	0.50	0.33
	liquidity	0.22	-0.02		industry	0.70	0.60
	fiscal	0.95	0.94		liquidity	0.35	0.13
	vix	0.72	0.63		fiscal	0.92	0.89
					vix	0.67	0.55
Japan	bond	0.48	0.28	Ireland	bond	0.54	0.39
	stock	0.67	0.55		stock	0.68	0.57
	money	0.76	0.67				
	cpi	0.24	-0.05		cpi	0.22	-0.05
	industry	0.43	0.21		industry	0.41	0.21
	liquidity	0.52	0.33		liquidity	0.61	0.47
	fiscal	0.94	0.92		fiscal	0.95	0.93
	vix	0.70	0.59		vix	0.65	0.53
UK	bond	0.51	0.33	Netherlands	bond	0.56	0.40
	stock	0.78	0.70		stock	0.54	0.37
	money	0.63	0.50		cpi	0.29	0.03
	cpi	0.64	0.51		industry	0.73	0.62
	industry	0.53	0.36		liquidity	0.45	0.24
	liquidity	0.82	0.76		fiscal	0.92	0.88
	fiscal	0.95	0.94		risk	0.52	0.34
	vix	0.61	0.47		vix	0.65	0.51

Table VII.6.. Variance decomposition for the entire dataset
Shocks originated in the United States

		Stocks			VIX			Liquidity			Bonds			Money Market		
Periods after shock		1	4	10	1	4	10	1	4	10	1	4	10	1	4	10
Bonds	World	7.28	5.09	3.42	0.05	0.02	0.01	5.28	3.06	1.99	32.20	25.01	16.48	5.23	5.24	3.59
	Crisis	12.34	8.56	5.58	0.74	0.73	1.13	28.03	20.80	12.11	31.69	23.84	7.62	51.96	46.46	18.16
	Greece	9.34	5.96	3.84	0.75	0.94	1.33	13.28	7.72	3.92	11.07	6.15	2.99	10.12	10.51	6.50
	Eurozone	0.26	0.32	0.23	1.31	1.25	1.24	1.57	1.29	1.21	1.37	3.22	3.01	2.19	5.00	4.65
Stocks	World	55.97	47.11	35.95	0.86	1.94	1.50	11.42	5.72	2.69	1.63	1.07	5.91	6.61	7.01	6.14
	Crisis	50.31	48.22	43.06	1.07	0.17	0.58	3.33	1.08	0.18	0.19	3.63	8.37	0.36	0.23	3.82
	Greece	6.89	5.77	4.08	0.71	0.84	0.74	2.51	1.56	0.81	2.78	1.90	0.78	2.14	2.61	1.32
	Eurozone	11.86	12.48	12.91	1.63	2.17	2.38	0.79	0.60	0.46	0.07	0.93	1.14	0.11	0.71	1.99
Money	World	1.54	1.52	1.12	0.73	0.67	0.64	3.77	4.31	3.51	1.71	0.68	0.33	23.63	14.01	7.29
	Crisis	22.39	15.90	10.23	5.98	6.46	6.14	26.65	17.11	8.95	38.64	26.29	11.43	51.67	52.71	25.89
	Greece	3.01	2.02	1.21	0.61	0.50	0.49	1.12	0.29	0.14	0.31	0.67	1.85	0.41	0.13	0.74
	Eurozone	0.14	0.07	0.01	0.01	0.00	0.00	0.13	0.20	0.04	1.96	2.27	1.75	0.06	0.17	0.10

Table VII.7.. Variance decomposition for the entire dataset
Shocks originated in Greece

		Stocks			VIX			Liquidity			Bonds		
Periods after shock		1	4	10	1	4	10	1	4	10	1	4	10
Bonds	World	1.95	1.80	1.54	4.47	4.96	3.01	4.28	1.63	0.95	16.19	4.56	2.92
	Crisis	4.22	2.21	8.95	24.11	23.22	12.45	20.76	7.79	6.61	20.86	60.76	90.74
	Greece	0.17	3.72	3.65	7.40	28.07	22.96	3.51	1.23	0.58	94.42	26.95	17.27
	Eurozone	3.14	1.38	0.89	5.64	3.84	3.37	0.16	0.22	0.18	0.77	11.07	10.12
Stocks	World	8.70	4.16	3.54	4.19	4.37	2.76	3.44	1.15	0.61	7.49	2.36	1.21
	Crisis	14.55	11.56	11.10	1.08	0.08	0.38	1.79	0.56	-1.05	-1.55	2.53	0.55
	Greece	92.19	70.21	64.74	5.87	3.94	4.48	0.23	1.47	2.13	0.97	3.87	1.90
	Eurozone	0.43	0.43	0.51	0.32	0.12	0.10	0.01	0.01	0.12	0.02	0.16	0.31
Money	World	0.15	0.18	0.06	5.67	3.52	2.43	1.65	0.98	1.32	3.86	1.02	0.62
	Crisis	10.71	6.39	3.37	39.87	32.33	20.04	16.89	5.33	3.17	47.99	11.80	4.39
	Greece	0.13	0.75	0.58	0.02	2.49	1.73	0.01	0.14	0.11	0.61	0.25	0.10
	Eurozone	0.31	0.99	1.07	0.08	0.35	0.21	0.02	0.00	0.19	0.41	0.31	0.69

Table VII.8.. Variance decomposition since the onset of the Eurzone

		Stock			VIX			Liquidity			Bonds		
Periods after shock		1	4	10	1	4	10	1	4	10	1	4	10
Shocks originated in the United States													
Bonds	World	3.88	2.83	2.39	5.45	6.30	3.84	0.70	0.91	1.36	25.98	22.71	17.86
	Crisis	19.69	0.17	4.89	10.73	9.64	8.26	6.82	15.02	9.52	15.53	7.75	8.40
	Greece	1.24	1.79	1.22	16.42	9.37	5.85	1.99	2.46	1.47	0.94	0.55	1.24
	Eurozone	0.18	0.11	0.10	0.07	2.22	3.12	0.08	0.06	0.13	0.05	0.10	0.06
Stocks	World	21.96	19.27	17.58	6.56	6.51	4.48	2.16	1.48	1.13	10.44	9.25	7.69
	Crisis	0.11	4.90	7.66	0.12	0.87	1.55	6.76	2.78	2.80	6.69	12.36	14.63
	Greece	0.49	0.94	0.55	5.71	5.74	3.63	7.48	6.40	6.60	0.29	1.09	0.66
	Eurozone	0.53	1.06	1.25	0.32	0.45	0.31	0.63	0.26	0.08	2.24	4.23	4.51
Shocks originated in Greece													
Bonds	World	2.21	1.92	1.69	1.35	1.62	1.24	0.63	0.30	0.51	6.46	1.76	1.46
	Crisis	9.22	11.29	8.20	22.84	10.88	5.59	3.84	6.02	9.17	10.32	75.53	97.16
	Greece	1.19	7.81	7.71	13.34	19.83	13.56	0.04	0.41	0.66	94.58	30.64	21.43
	Eurozone	0.35	0.95	0.73	0.89	0.85	0.55	0.01	0.14	0.90	0.04	1.43	1.04
Stocks	World	7.30	4.74	3.39	0.24	1.31	1.31	0.48	0.54	1.03	4.56	1.30	1.15
	Crisis	12.57	3.51	0.50	7.29	12.89	14.32	3.54	0.50	0.19	3.60	2.81	1.08
	Greece	61.62	43.11	40.49	12.15	11.97	9.42	5.28	8.75	10.60	6.12	1.77	1.57
	Eurozone	0.53	0.42	0.40	2.19	4.58	5.18	-0.06	-0.02	0.22	0.19	0.28	0.79

Chapter VIII.

Final Remarks

What have we learned, and to what end? Even though the research topics presented in this dissertation are rather differentiated, the quintessence of each contribution and the relevance in the context of economic research is briefly highlighted in the following.

A novelty to the business cycle literature is the dynamic stochastic general equilibrium model with inventories successfully estimated using Bayesian techniques on U.S. data. The results of our New Keynesian model differ compared to the ones estimated via impulse response matching or performing a calibration exercise. In the same manner, models without inventories have different implications. While many results stay within the range of common findings of the macroeconomic profession, some do not.

Inventories change the behaviour of the marginal cost which affects the price level and hence monetary policy, as our results show. Employing data on inventories for the estimation seems crucial to uncover this fact. As technology shocks contribute most to fluctuations in economic activity in the medium and long run, so do investment shocks play a major role in the short run. Interestingly, with investment in capital and inventories we reveal that both investment shocks have different impacts on the economy. Furthermore, there are short run variations in inventory holding that need to be investigated, but although we need more research on inventories, my contribution is a first step in this interesting direction. However, as our results do not strongly reject basic findings of the literature, whether inventories should be neglected for the sake of simplicity depends on the research question.

An extended version of the inventory model with different stages of production where goods can be stored at each stage of production is used to analyse the developments underlying the Great Moderation. By means of Bayesian estimation and U.S. time series, we compare the outcomes and implications for the two sub-samples with different volatilities. Indeed, both periods differ regarding the shocks and policy parameters and thus the impulse responses and variance decomposition deviate.

We confirm that the efficiency of storing has been improved since the 1980s, but counterfactual exercises reveal that the improvements in inventory management as well as monetary policy contributed only slightly to the Great Moderation. Therefore, good luck is the most appropriate hypothesis of the three discussed in the literature. However, according to our results, a rise in cost of formation and usage of productive capital as well as more flexible labour markets contribute most to the Great Moderation phenomenon. Possible explanations for these developments in capital costs are a rise in complexity in production processes, a rise in fixed cost associated with varying effective capital, subdivision in expenditures for long-term investment projects, and rigidities regarding adjustments of investment projects according to economic changes. Further investigations should focus on the microeconomic developments in investments and capital-intensive production processes.

Turning from the estimated structural closed-economy model to an empirical setup, in the third study

we employ a dynamic hierarchical factor model to identify the degree of synchronization among international inflation rates. In contrast to common dynamic factor models, the hierarchical model does not rest on the assumption of orthogonal factors. This new methodology a priori allows a correlation of the different unobserved factors. Thus, the global factor could co-move with regional factors, an approach that seems more appropriate in a globalized world for logical reasons.

Using different classifications of consumer price indices and distinguishing between industrialized and emerging economies, our findings strongly suggest that inflation is rather a local phenomenon than a global one. Food and energy prices depend more on global developments than prices of consumer baskets without food and energy, but the effect is quite small. Consequently, monetary authorities can be or actually have been successful in fighting inflation. Furthermore, the results suggest that core inflation might be a more reliable indicator for national inflation pressure than food or energy prices. The extent to which flexible exchange rates and inflation targeting support this outcome could be subject for future research.

Another application of the dynamic hierarchical factor model is undertaken for international capital flows. We apply data on three different types of capital inflows: foreign direct investment, portfolio investment and other inflows for a variety of countries. Besides the categorization of different capital inflows we choose to group the observations differentiated by regional proximity.

Our results demonstrate, first of all, that capital flows are primarily driven by idiosyncratic components, i.e. developments specific to a country and the type of capital inflow. Global factors generally do not matter. We therefore conclude that capital flows depend rather on pull factors such as macroeconomic fundamentals than on push factors like global excess liquidity. As a result, economies are not at the global economy's mercy and domestic policy makers are able to take actions in order to prevent or attract capital inflows.

Chapter IX.

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Affidavit

„Ich erkläre hiermit, dass ich die vorgelegten und aufgelisteten Aufsätze selbstständig und nur mit den Hilfen angefertigt habe, die im jeweiligen Aufsatz angegeben oder zusätzlich in der Liste aufgeführt sind. In der Zusammenarbeit mit den angeführten Koautoren war ich mindestens anteilig beteiligt. Bei den von mir durchgeführten und in den Aufsätzen erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der Satzung der Philipps Universität Marburg zur Sicherung guter wissenschaftlicher Praxis niedergelegt sind, eingehalten.“

Ort, Datum

Unterschrift

In dieser Dissertation enthaltene Aufsätze

- [1] Bernd Hayo and Britta Niehof. ‘Identification Through Heteroscedasticity in a Multicountry and Multimarket Framework’, MAGKS Diskussionspapier Nr. 24-2011.
- [2] Bernd Hayo and Britta Niehof. ‘Studying Spillovers in a New Keynesian Continuous Time Framework with Financial Markets’, MAGKS Diskussionspapier Nr. 42-2013.
- [3] Bernd Hayo and Britta Niehof. ‘Analysis of Monetary Policy Responses After Financial Market Crises in a Continuous Time New Keynesian Model’, MAGKS Diskussionspapier Nr. 21-2014.
- [4] Bernd Hayo and Britta Niehof. ‘Monetary and Fiscal Policy in Times of Crises: A New Keynesian Perspective in Continuous Time’, MAGKS Diskussionspapier Nr. 55-2014.
- [5] Britta Niehof. ‘Spillover Effects in Government Bond Spreads: Evidence from a GVAR Model, MAGKS Diskussionspapier Nr. 58-2014’